Oceanus

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THROUGH THE LENS

◄ A school of barracuda swims near a reef off Kimbe Island, Papua New Guinea, where WHOI biologist Simon Thorrold is working on a novel method using otoliths (fish ear bones) to track the movements of fish over their lifetimes. Read more at www.oceanusmag.whoi.edu.

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NOTE FROM THE EDITORS

More than 200,000 people killed. Another 100,000 unaccounted for. Millions of lives terribly disrupted and billions of dollars in damage. The Dec. 26 Indian Ocean tsunami shattered our usual landlocked perspective, brutally reminding us that we live on a dynamic planet, with a dynamic ocean. In this issue of *Oceanus*, we devote a special section to the scientific lessons learned from the Indian Ocean tsunami and to revitalized efforts to build ocean-monitoring systems.

This issue marks the debut of a newly designed format for *Oceanus;* magazines are dynamic, too. *Oceanus* was first published in 1952 as a 16-page typewritten document to provide "a worthwhile reference to modern oceanographic exploration." That concise philosophy endures, but in a new medium (online at oceanusmag.whoi.edu) and in a new print edition. Let us know what you think at oceanusmag@whoi.edu.

Cover: WHOI engineer Will Ostrom (left) and technician Kris Newhall conduct sea trials on a new mooring system called "Gumby" because of its ultra-flexible hoses. Embedded in those hoses are electrical conducting wires that make it possible to transmit high-rate, real-time data from the ocean floor to shore. Researchers plan to install the mooring—linked to a seafloor seismic-monitoring instrument—in the tsunami-prone Caribbean in 2006 (see page 20). Photo by Jayne Doucette, WHOI.

Even sperm whales get the bends

It seemed only natural that deep-diving sperm whales would be immune from decompression illness, or "the bends"—the painful, sometimes fatal condition that human divers suffer when they surface too rapidly. But the whales may be as susceptible as land mammals, according to a new study by biologists at Woods Hole Oceanographic Institution.

Michael Moore and Greg Early examined bones from 16 sperm whale skeletons archived in museums and detected telltale patches of dead bone (osteonecrosis)—most likely caused by nitrogen bubbles that form when divers decompress too rapidly.

Only the bones of whale calves did not show signs of osteonecrosis, the scientists found, and the bone damage became more severe in larger (older) whales—an indication that osteonecrosis caused by decompression illness is a chronic, progressive disease among sperm whales.

When air-breathing mammals dive to high-pressure depths, the nitrogen in their bodies becomes supersaturated in their tissues. If they rise too quickly, the pressure is released too suddenly. The nitrogen reverts to gas, forming bubbles, or emboli, which can obstruct blood flow and lead to bone damage.

Moore and Early launched their study in 2002 after a necropsy of a sperm whale found dead on a Nantucket Beach revealed evidence of osteonecrosis. Intrigued, they decided to examine as many sperm whale skeletons as possible.

Their inventory included whales from the Pacific and Atlantic, and whales that died as long as 111 years ago—so the newly found phenomenon is neither localized nor recent.

Sperm whale dives typically last about an hour, but can be as long as two hours. Whales dive to 1,000 to 2,000 meters (3,300 to 6,600 feet) in search of their preferred prey: squid. The scientists theorize that the whales normally manage their surfacing behavior to avoid decompression problems. But if noxious sounds—from sonar, for instance, or oil exploration airguns—disrupt their usual behavior and provoke fast surfacing, the whales risk problems from nitrogen emboli. Such sounds are more common today.

Moore and Early reported their findings in the journal *Science*. Their study was supported in part by the NOAA Fisheries John H. Prescott Marine Mammal Rescue Assistance Program.

—*Lonny Lippsett*

▲ A necropsy of a dead sperm whale found on Nantucket in 2002 revealed evidence of decompression illness, or "the bends," which may be a chronic, progressive disease among deep-diving sperm whales.

Tom Kleindinst, WHOI

◄ A spherical lesion in a rib of a dead sperm whale was likely caused by nitrogen bubbles that formed when the whale rose too rapidly from high pressure in the depths. The bubbles block blood flow and damage bone.

A lone voice crying in the watery wilderness

In 1989, a team of WHOI biologists detected an unusual sound in the North Pacific Ocean. It had all the repetitive, low-frequency earmarks of a whale call, but at a unique frequency—52 hertz—far higher than the normal 15- to 25-hertz range of blue or fin whales. They recorded it again in 1990 and 1991.

With the end of the Cold War, the U.S. Navy partially declassified its Sound Surveillance System (SOSUS), a hydrophone network built to monitor Soviet submarines. Using SOSUS, the WHOI team picked up the lone call of the same 52-hertz whale and has tracked it every year since as it has roamed widely through the North Pacific, from offshore California to the Aleutian Islands off Alaska.

"It is perhaps difficult to accept that if this was a whale, that there could have been only one of this kind in this large oceanic expanse, yet in spite of comprehensive, careful monitoring year-round, only one call with these characteristics has been found anywhere, and there has been only one source each season," the scientists wrote in their study, published in *Deep-Sea Research*. The research was conducted by Mary Ann Daher, Joseph George, David Rodriquez, and William Watkins. (Watkins, who pioneered the field of marine mammal acoustics with William Schevill at WHOI in the 1950s, died in September 2004).

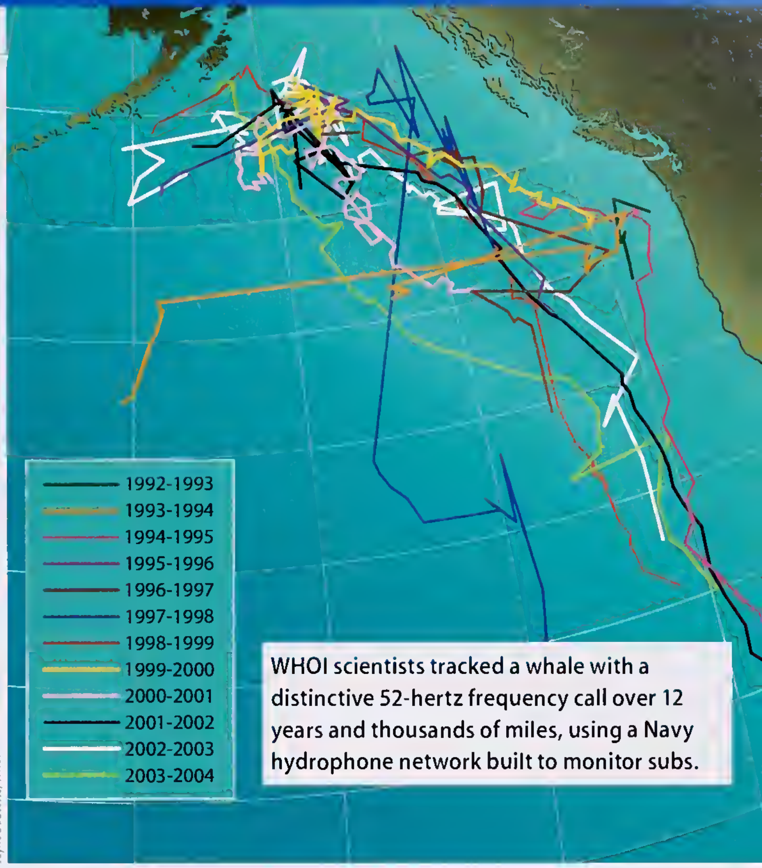
The 52-hertz call may be due to a malformation, or the whale may be a hybrid of two species, the scientists speculated, but whatever the cause, it "has provided an unusual opportunity to document the seasonal activities of what we believe to be an individual whale."

Every year over the 12-year span, the WHOI team has picked up the 52-hertz call sometime between August and December and monitored it until the whale swam out of range, always within a few weeks in January or early February. Traveling 31 to 69 kilometers per day, it was tracked over a minimum of 708 kilometers (440 miles) one season and a maximum of 11,062 kilometers (6,874 miles) in 2002-03.

"The usual tracking for an individual whale last hours at best," the scientists said.

—*Lonny Lippsett*

The research has been supported over the years by the U.S. Navy, the U.S. Army Corps of Engineers, the Department of Defense, and the National Marine Fisheries Service. "WHOI maintained the continuity of the program between increments of formal support," the scientists said.



WHOI scientists tracked a whale with a distinctive 52-hertz frequency call over 12 years and thousands of miles, using a Navy hydrophone network built to monitor subs.

Jayne Doucette, WHOI


◄ The WHOI team that tracked the 52-hertz whale included Mary Ann Daher and the late William Watkins, who died in 2004 at age 78. Watkins built the first instrument to record marine mammals at sea and, over a 46-year career at WHOI, pioneered many fundamental methods to locate, identify, and track marine mammals. Said WHOI biologist Peter Tyack: "Bill Watkins, more than anyone, has brought the voices of mammals living under the sea to the ears of those of us who live in air."

Tom Kleindinst, WHOI

A "thinking map" of North America

For geologist Brian Tucholke, creating a new Geologic Map of North America was a 23-year adventure.

The new map, published in February by the Geological Society of America (GSA), illustrates the geology of approximately 15 percent of Earth's surface and spans an area from the North Pole to Venezuela and from Ireland to Siberia. It was a cooperative effort by Tucholke, who mapped the seafloor geology, and John C. Reed Jr. of the U.S. Geological Survey and John O. Wheeler of the Geological Survey of Canada, who compiled the map's continental geology. The last such map was published in 1965.

▲ A detail from the newly published GSA Geologic Map of North America.

"This is the first continent-scale geologic map of North America published since the plate tectonic revolution," said Tucholke, a senior scientist in the WHOI Geology and Geophysics Department. "It shows the seafloor geology for the first time and presents a whole new view of the geology of North America in a plate-tectonic context."

In 1981 GSA officials asked Tucholke if he thought compiling the seafloor data for a new North America map was realistic, and if he would do it. "I answered yes to both," he said. "I didn't realize what I was getting into."

Tucholke began the work in 1982, doing everything from scratch, with only minor funding for the project considering the magnitude of the task. With small amounts of support from the Office of Naval Research, the National Science Foundation, GSA, and WHOI, he did much of the work during evenings and weekends on his own time, extracting information from published literature, unpublished data from any sources he could "mine," and contributions he solicited from other scientists.

The 6-by-6-foot map is printed in 11 colors with about 700 shades and patterns. It distinguishes more than 900 rock units, 110 of which are offshore, and it depicts more than seven times as many on-land units as its 1965 predecessor. But perhaps its most significant additions are detailed geological attributes of the seafloor, including such diverse features as spreading centers, subduction zones, seamount chains, major faults, submarine drainage patterns, and ages and lithology of outcrops—all thanks to Tucholke.

In a pamphlet published with the map, Tucholke and his co-authors say the new geologic map is essentially a "thinking map" for earth science professionals, students, and the public that "undoubtedly will lead to new ideas about how the geology of North America should be interpreted."

"This, in turn, will make possible new insights into the evolution of the continent," they wrote. "In practical terms, it will generate new exploration strategies for the discovery of mineral and energy resources and will facilitate development of better ways of assessing and mitigating environmental risks."

—*Shelley Dawicki*

WHOI scientist Brian Tucholke compiled the seafloor data that were incorporated into the new geologic map.

Where scientists and pirates meet

Photos: Tom Kleindinst, WHOI

▲ Researcher Mary Lardie flame-seals a tube, preparing to carbon-date a wood sample (right) from the pirate Blackbeard's flagship, *Queen Anne's Revenge*, at the National Ocean Sciences Accelerator Mass Spectrometry Facility at WHOI. The ship ran aground offshore Beaufort, N.C., in 1718 and settled into the sands. In 1996, hurricanes and nor'easters scoured the sands away, and divers discovered the wreck, which is now the site of a long-term archaeological investigation. The NOSAMS Facility analyzes samples for researchers around the country.

The forecast for 'marine snow'

WHOI geochemist Ken Buesseler heads to the North Pacific in July to lead a cruise to track "marine snow" through the "twilight zone." This little-known but fundamental process could play a key role in understanding and mitigating global warming.

"Marine snow" consists of particles—composed of decomposed microscopic plants, animals, and fecal pellets—that "rain" from sunlit surface waters to the deep ocean. On the way, the particles sink through the "twilight zone," a dim, little-studied ocean region that ranges from the surface down to 500 to 1,000 meters (1,640 to 3,280 feet).

Blooms of photosynthetic phytoplankton draw huge amounts of carbon from the atmosphere to live and grow. When they die or are eaten, a small portion of that carbon, in the form of marine snow, is delivered into long-term storage in the deep ocean or buried on the seafloor. This "biological pump" already helps to reduce the buildup of atmospheric carbon dioxide, a greenhouse gas, and it has sparked controversial proposals to add more nutrients to the oceans—to stimulate plankton growth, rev up the biological pump, and curtail global warming.

Ken Buesseler, WHOI

► To sample zooplankton from surface to depths, scientists tow a system with 10 separate nets that they open and close with a shipboard computer.

Buesseler was chief scientist for two cruises north of Oahu in 2004, sponsored by the U.S. National Science Foundation and other agencies. Using a variety of instruments, a multi-institutional and multidisciplinary team of scientists and engineers collected specimens and data to learn where marine particles come from, how fast and deep they sink, and how they break apart or are consumed by animals or bacteria on the way down. The project, dubbed VERTIGO (VERtical Transport In the Global Ocean), continues this summer with a cruise to a contrasting ocean setting near Japan.

—Lonny Lippsett

Seeing red in coastal New England waters

▲ WHOI researchers took measurements of water temperature, salinity, and depth and collected water samples throughout the Gulf of Maine on the first cruise funded by the Center for Oceans and Human Health (see below).

Two weeks before coastal managers started closing Massachusetts shellfish beds in mid-May, WHOI researchers found that they had sailed right into the region's worst harmful algal bloom since 1972.

Within hours of departing Woods Hole on R/V *Oceanus* for an expedition to study harmful algae, a team led by physical oceanographer Dennis McGillicuddy and marine biologists Deana Erdner and Bruce Keafer found thousands of toxic algal cells in every liter of water sampled from the ocean. Using novel genetic techniques and sophisticated computer models, scientists rapidly detected and quantified the amount of harmful algae in offshore waters and offered predictions of where ocean currents were likely to carry the cells.

In June, the researchers received emergency federal funding to continue and extend their surveys on the coastal vessel *Tioga*, as the record-setting bloom stretched from Maine to Martha's Vineyard. Read more at oceanusmag.whoi.edu.

Scientists team up to study ocean's effect on health

Researchers from Woods Hole Oceanographic Institution, the Marine Biological Laboratory (MBL), and the Massachusetts Institute of Technology (MIT) have embarked on a novel collaboration to investigate harmful algal blooms, ocean-borne pathogens, and potential pharmaceuticals from marine sources.

Now in its first year, the Woods Hole Center for Oceans and Human Health is one of four such centers around the country, created by the National Science Foundation (NSF) and the National Institute of Environmental Health Sciences (NIEHS) to study "risks and remedies from the sea."

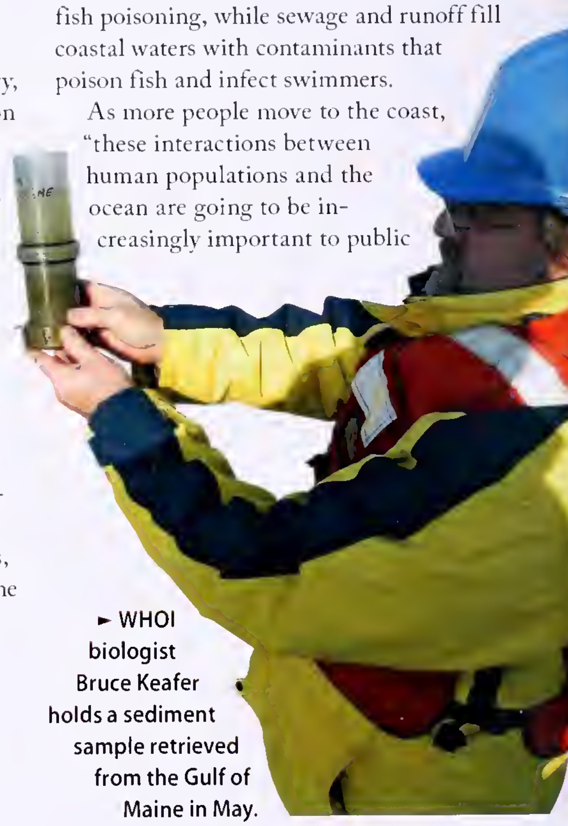
The Woods Hole center will receive $6.25 million over five years to concentrate on algae and pathogens that affect coastal New England, using local waters as a model for temperate coastal oceans throughout the world.

Human health and welfare are intimately tied to the oceans. Fisheries yield 130 million tons of food each year, and biologists and chemists continue to uncover useful medicinal compounds among snails, sponges, and other marine creatures. At the same time, exploding populations of toxic algae cause respiratory problems and shellfish poisoning, while sewage and runoff fill coastal waters with contaminants that poison fish and infect swimmers.

As more people move to the coast, "these interactions between human populations and the ocean are going to be increasingly important to public

Tom Kleindinst, WHOI

◄ WHOI biologist John Stegeman (right) and physical oceanographer Dennis McGillicuddy head the new Woods Hole Center for Oceans and Human Health.



► WHOI biologist Bruce Keafer holds a sediment sample retrieved from the Gulf of Maine in May.

health," said John Stegeman, director of the new center and chair of the WHOI Biology Department.

Advisors to NSF and NIEHS found a "scientific gap" in the state of knowledge about the ocean's influence on human health and called for a merger of traditional biomedical research with physical ocean science, said Frederick Tyson, the center's program administrator at NIEHS. Four Centers for Oceans and Human Health have been established: at WHOI, the University of Hawaii, the University of Miami, and the University of Washington.

"The ocean is a turbulent fluid medium that's changing all the time," said Dennis McGillicuddy, a WHOI physical oceanographer and the center's deputy director. "In order to make significant progress in health concerns, we have to grapple with how physics, biology, and chemistry intersect and interact. It's really a fundamentally new direction for this research."

Two Woods Hole projects focus on *Alexandrium*, a harmful alga that blooms yearly in the Gulf of Maine, producing a potent toxin that can accumulate to dangerous levels in shellfish. WHOI Senior Scientist Don Anderson and collaborators from the center's genomics facility—housed at MBL—will use DNA analysis to determine if some *Alexandrium* populations are more toxic than others, and will explore how varying ocean conditions encourage or inhibit the algae's growth. Anderson is working closely with McGillicuddy, who is mapping how coastal currents distribute *Alexandrium*, with a long-term goal of developing ways to predict blooms.

MIT environmental engineer Martin Polz is collaborating with WHOI physical oceanographer James Lerczak to determine the conditions that encourage the growth of virulent strains of *Vibrio*, a naturally occurring bacterium that can infect swimmers' eyes, ears, and wounds. *Vibrio* causes 95 percent of seafood-related death in the United States.

WHOI biologist Rebecca Gast and MBL biologist Linda Amaral-Zettler are investigating the distribution and survival of human pathogens such as *Giardia* to learn how to predict where and when they can be found.

—Andrea Baird

The great flood of New York

Trapped behind the Adirondack Mountains and a tremendous ice sheet, glacial Lake Iroquois was three times the size of modern Lake Ontario. Then, 13,350 years ago, the natural ice dam collapsed. Floodwaters rushed down the Hudson River Valley; past modern Manhattan, Brooklyn, and Staten Island; through an earthen dam where the Verrazano Narrows Bridge now stands; and across another hundred miles into the North Atlantic. The water level in Lake Iroquois dropped 120 meters (400 feet), and rocks the size of Volkswagens moved hundreds of miles downstream.

Jack Cook, WHOI

▲ An ice sheet that dammed a large Ice Age lake collapsed 13,350 years ago, sending a flood down the Hudson River Valley. The flood of fresh water into the ocean also caused dramatic climate changes.

Beyond reshaping the landscape, the catastrophic flood also had dramatic impacts on Earth's climate. It may have triggered a brief but global period of colder climate known as the Intra-Allerod Cold Period, said Jeff Donnelly, a geologist at Woods Hole Oceanographic Institution. The torrent from the glacial lake would have thundered into the North Atlantic, adding a vast freshwater "lid" on the ocean surface that could have rearranged ocean circulation and changed climate patterns, said Donnelly, who is a fellow of both the Ocean and Climate Change Institute and the Coastal Ocean Institute at WHOI.

Scientists have long suspected that large discharges of glacial water into the ocean could drive climate fluctuations, but linking discharge events like the Hudson flood with individual climate changes has been difficult because of the challenges in pinpointing the location, timing, and amount of the discharges.

Donnelly and colleagues analyzed sediments from the Hudson River Valley, which extends under water on the continental shelf (see map). On huge sediment lobes on the shelf, where sediments are normally the size of sand grains, they found car-sized boulders—which were likely pushed there by the great flood.

The team also analyzed ancient pollen deposited by the flood in sediments near the Tappan Zee Bridge and the Holland Tunnel, as well as walrus fossils buried by the flood in the offshore sediment lobes. The results precisely dated—for the first time—the discharge from Lake Iroquois and linked it to the Intra-Allerod Cold Period.

Donnelly and colleagues described the historic flood and its effects in a February 2005 paper in the journal *Geology*.

—Shelley Dawicki

Funding for the research was provided by The John E. and Anne W. Sawyer Endowed Fund, the Office of Naval Research, the WHOI Postdoctoral Scholar Program, The J. Lamar Worzel Assistant Scientist Fund, and the WHOI Ocean and Climate Change Institute.

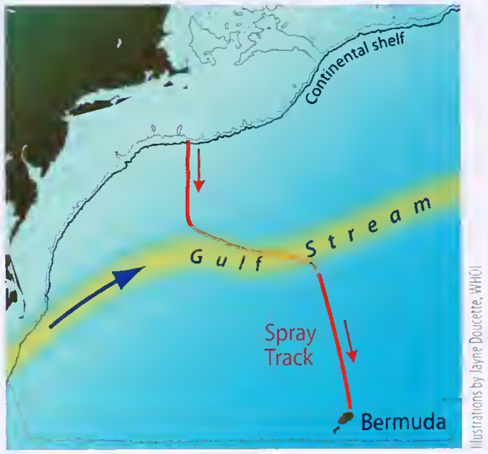
A glide across the Gulf Stream

Remote-controlled Spray's historic step heralds new era of ocean exploration

For 50 nights last fall, Breck Owens often slept with a laptop computer on his chest. It was a critical link that let Owens communicate with a torpedo-shaped glider on a pioneering mission across the turbulent Gulf Stream.

"Without constant two-way communication, this mission would have been dubious at best," said Owens, a physical oceanographer at Woods Hole Oceanographic Institution. Seven sleep-deprived weeks on Cape Cod paid off when the glider safely arrived offshore Bermuda, a 965-kilometer (600-mile) trip that proved the viability of a remote-controlled glider called Spray.

"The Atlantic just roars," said Russ Davis, Owens' collaborator, a physical oceanographer at the Scripps Institution of Oceanography. "So the whole goal was to guide this slow-moving, 6-foot aluminum glider from south of Nantucket to Bermuda without it getting swept to England first."



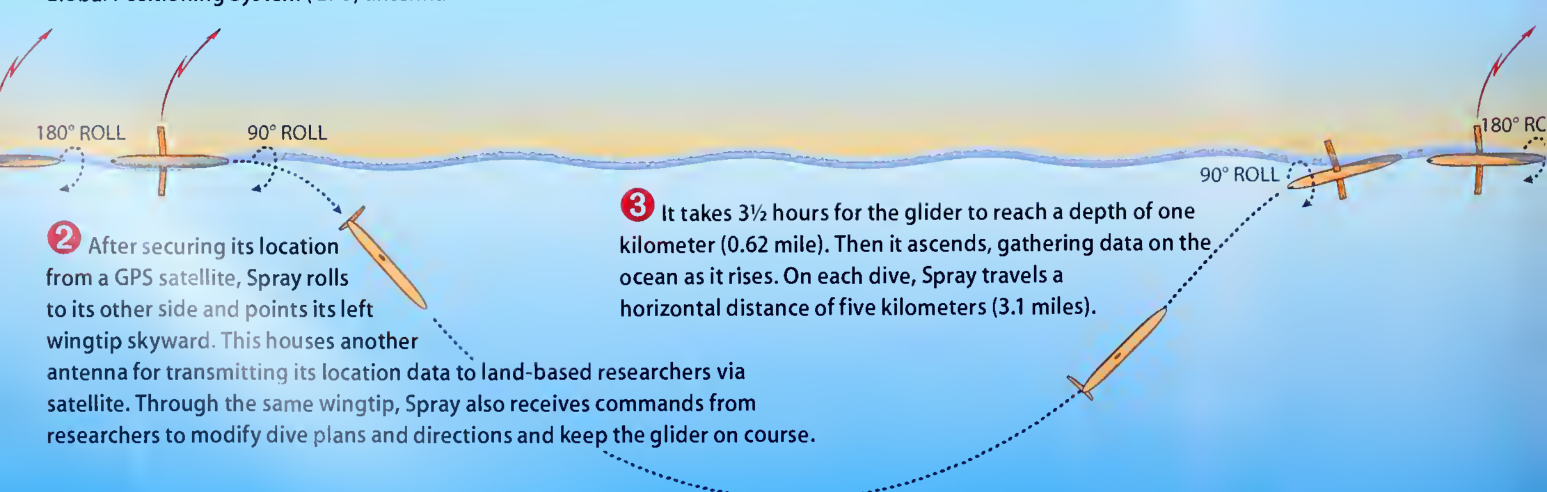
▲ The Spray glider was launched in September 2004 south of Nantucket and recovered seven weeks and 965 kilometers (600 miles) later off Bermuda. It was the first time a remote-controlled glider crossed the Gulf Stream.

News of the first successful Gulf Stream crossing by a glider has caused a ripple among scientists, who recall the dream of famed WHOI oceanographer Henry Stommel. Nearly two decades ago, Stommel imagined fleets of unmanned robots roaming over hundreds of kilometers of remote seas and repeatedly diving below the surface to gather water temperature, salinity, and other data on the ocean over weeks and even months. Such roving robots would provide more frequent and comprehensive data coverage across the ocean's length and breadth to develop, for example, a more complete picture of ocean circulation and more accurate weather and climate forecasts.

"We can't be at sea all the time, so the next best thing is to send robots out to do work for us," Owens said. He and Davis had lofty aspirations for Spray. Its name honors the sloop *Spray*, sailed by Captain Joshua Slocum in the mid-1890s during the first solo circumnavigation of the planet.

"It took time for technology to catch up with Stommel's dream," Owens said. The same satellite and electronics technology that have given us cell phones and the Internet have opened new doors to scientists researching the oceans. Two satellite-based systems in particular proved helpful when

1 Spray resembles a whale moving through the water, repeatedly submerging and resurfacing. Between each dive, Spray floats for about 15 minutes on the surface and rolls on its right side to expose its right wingtip, embedded with a Global Positioning System (GPS) antenna.



2 After securing its location from a GPS satellite, Spray rolls to its other side and points its left wingtip skyward. This houses another antenna for transmitting its location data to land-based researchers via satellite. Through the same wingtip, Spray also receives commands from researchers to modify dive plans and directions and keep the glider on course.

3 It takes 3½ hours for the glider to reach a depth of one kilometer (0.62 mile). Then it ascends, gathering data on the ocean as it rises. On each dive, Spray travels a horizontal distance of five kilometers (3.1 miles).

researchers began designing Spray in 1998: Global Positioning System (GPS) satellites and Iridium satellites, built respectively for navigation and communication uses.

Gliders resemble large model airplanes, with cone-shaped noses and flexible wings. Moving at a speed of a half-knot, Spray dives every three miles and collects data during its half-mile ascent back to the surface.

To keep Spray streamlined, prevent snags, and protect against corrosion, it was built without external moving parts or motors. Spray moves by altering buoyancy. To ascend, Spray uses a hydraulic pump to move four cups of mineral oil between two bladders. The oil's shift increases the glider's volume, making it less dense than surrounding water. To adjust Spray's pitch or roll, battery modules inside the vehicle shift to tilt the weight within the finely balanced vehicle. All equipment—from the compass in Spray's nose to the electronics equipment, sensors, and 12 kilograms (26 pounds) of batteries—are housed inside a lightweight aluminum shell.

Satellites have been orbiting since the late 1950s, but the oceans present a unique barrier: Radio waves cannot be transmitted through water.

"We had to figure out a way to get around all that water," Davis said.

On Sept. 11, 2004, the scientists launched the 51-kilogram (112-pound) glider from Nantucket and watched it head south. Between each dive, Spray floated for about 15 minutes on the surface and rolled on its right side to expose its right wingtip, embedded with a GPS antenna.

After securing its location from a GPS satellite, it rolled to its other side and pointed its left wingtip skyward. This housed another antenna for transmitting its location data to Owens via the Iridium satellite.

Through the same wingtip, Spray also received commands from Owens containing modifications to dive plans. "We could tell it to head south awhile, then head southwest," he said. Ever mindful of storms, rip currents, and unusual eddies, Owens gathered weather and sea reports and provided Spray with the necessary directions to stay on course.

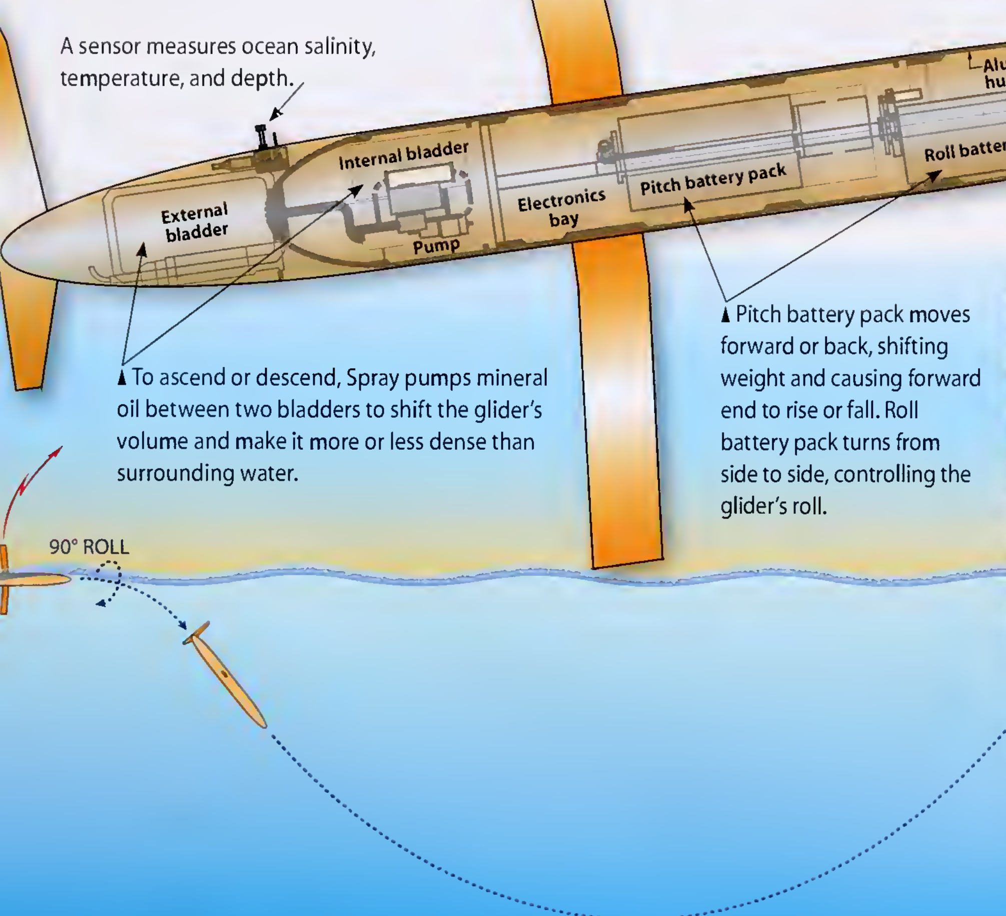
"Not only could I talk to the glider, but it could talk back," said Owens, who, despite two-way communication, admits to hang-wringing. "I was so worried about the glider that I slept with my laptop on my chest so I wouldn't miss anything."

On another field test in March 2005, Spray did not phone home on schedule one Sunday morning. It had failed to surface, but one of several fail-safe mechanisms kicked in to bring Spray back up. Owens and team jumped on a plane to Bermuda and hastily and luckily found a ship to recover the glider.

"By getting Spray back, we learned that a gear box failed and can figure out how to fix the problem," Owens said. "It would have been great if everything worked fine, but this is the cost of trying to use new technology to carry out innovative research."

With each new field test, scientists learn more about the vehicle's limits and make improvements. In the future, Spray will be able to handle more navigation tasks without as many updates from Owens. Otherwise, he said, "if I had to track and guide every one of those gliders, I would never get any sleep."

—Amy E. Nevala



Spray is 2 meters (6.5 feet) long and has a wingspan of 1.2 meters (3.9 feet).

▲ To ascend or descend, Spray pumps mineral oil between two bladders to shift the glider's volume and make it more or less dense than surrounding water.

▲ Pitch battery pack moves forward or back, shifting weight and causing forward end to rise or fall. Roll battery pack turns from side to side, controlling the glider's roll.

Benjamin Carr, WHOI

▲ WHOI oceanographer Breck Owens tracked and directed Spray's first successful journey across the Gulf Stream via his laptop computer.

Rambling and rumbling on

With machete in hand and 60 pounds of satellite receiver and tripod on his back, Jeff Standish looked up into the lush tropical brush that covered the volcano, up a steep escarpment, and up again to the summit 900 meters (3,000 feet) above sea level. Then he turned to Rhea Workman, a graduate student in the WHOI/MIT Joint Program, and said, "We're going up *where?*"

This whole expedition was Workman's idea. In 2002, she enlisted two Joint Program (JP) colleagues, Standish and Margaret Boettcher, to join her research project on the Samoan island of Ta'u. It was an extra project she had decided to take on—a side venture to her main research of exploring chemical clues in rocks to reveal how volcanic island chains form.

This wasn't the first time that Workman interrupted her studies for a volcano. As an undergraduate, she volunteered to work for a semester at the Hawaiian Volcano Observatory atop the highly active volcano of Kilauea, home of Pele, the Hawaiian goddess of volcanoes. The Earth moved under her feet. But that's not unusual around active volcanoes.

Within a volcano's underlying magma chamber, magma or gas continually surges or subsides, inflating or deflating the volcano's surface and deforming it in the process. These deformations are usually tiny, but they can be measured to evaluate what's going on inside the volcano and to predict whether it might erupt. Workman was a member of the Observatory's deformation research team.

After Workman came to WHOI, first in its Summer Student Fellowship Program, then as a graduate student, her research led her to Ta'u. Like the big island of Hawaii, Ta'u is the youngest and most volcanically active island in its chain. Roughly 10 kilometers wide by 6 kilometers long (4 by 6 miles), Ta'u's central volcano rises skyward. It was formerly dome-shaped, but one of its sides collapsed in landslides that cast debris all the way onto the seafloor. The landslides left a steep escarpment, which is primed for further catastrophic landslides—and possibly tsunamis—especially if it is disturbed by movements within the volcano.

Workman's idea was

Photo by Jeff Standish, WHOI

an active volcano in Samoa

to assess Ta'u's volcano and landslide hazard potential by measuring its subtle motions with Global Positioning Satellite receivers that can measure ground-motion changes as small as 1 centimeter (0.4 inches).

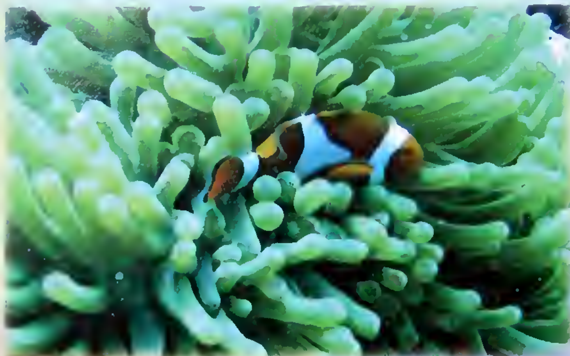
Like most ideas, this one required funding. Workman applied for a grant from a WHOI fund that seemed tailor-made: the Robert H. Cole Endowed Ocean Ventures Fund for special student projects. With OVF funding, Workman organized the expedition, conscripting the GPS equipment, as well as Standish and Boettcher. They installed GPS benchmarks throughout the island and located them precisely using GPS. That required a few machete-in-hand forays into the untrammeled interior, along the precarious escarpment, and to the top of the mountain.

"The experience of fieldwork is irreplaceable," Workman said. "You've got the rocks under your feet. You're concentrating on the landscape and developing an intuition that I don't think you can get any other way. You start to understand the landscapes and the volcanic processes just by being there and seeing how things look. And you've planned the whole thing and learned how to work with colleagues to get it done."

In the summer of 2004, Workman returned with JP student Matt Jackson to remeasure the benchmark locations. After her return, Workman scrambled to complete her Ph.D. dissertation in March. Now, as she moves on to postdoctoral work at the California Institute of Technology, she will analyze and compare her GPS measurements to detect telltale ground motion on Ta'u.

-Lonny Lippsett

Rhea Workman (left) uses a GPS satellite receiver to measure subtle deformations on the surface of Mount Lata, an active volcano on the Samoan island of Ta'u. One side of the formerly dome-shaped volcano collapsed in landslides, leaving a steep escarpment (below) that is primed for further catastrophic landslides.



Simon Thorrold, WHOI

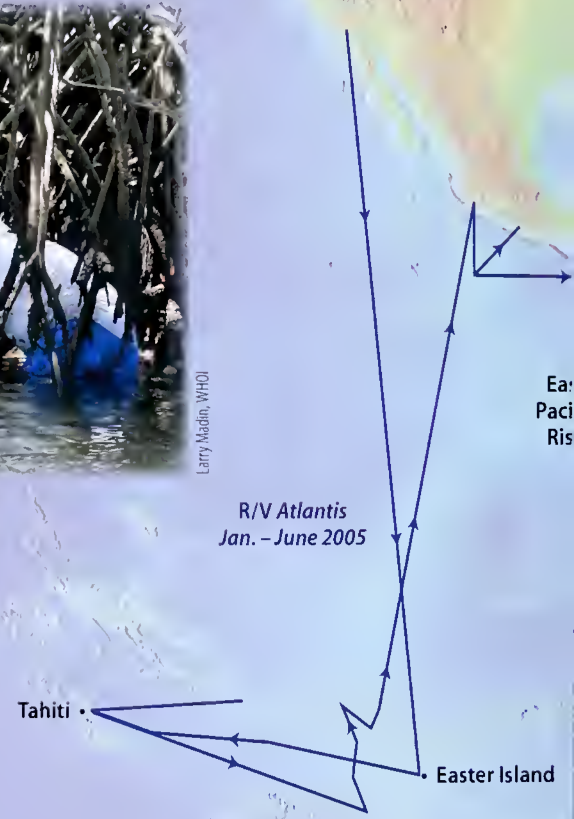
Reef to reef

Papua New Guinea—WHOI biologist Simon Thorrold injected pregnant female clownfish with a non-toxic chemical tag in April on a reef off Kimbe Island. The tag is incorporated into the ear bones (otoliths) of fish embryos and remains there throughout the fish's life. When the fish are caught, scientists can remove the otolith and detect the tag. The breakthrough technique reveals where fish were born and where they dispersed. Such knowledge is key for managing and protecting reef fisheries. Read more at oceanusmag.whoi.edu.

The root of the problem

Bahia Honda, Panama—WHOI biologist Jesús Pineda began a study in March of a coastal mangrove stand where (in contrast to many mangrove ecosystems) larvae of mollusks and crustaceans are unusually scarce. He is exploring a theory that naturally occurring chemicals from rainforest leaves kill the larvae. The study site is the new Liquid Jungle Lab, built by businessman Jean Pigozzi to host tropical research by scientists from WHOI and other institutions. Read more at whoi.edu/institutes/oli.

Larry Madin, WHOI



• Papua, New Guinea

Tyler Goepfert, WHOI

Tracing trace metals

Arabian Sea— WHOI marine chemists Jim Moffett and Tyler Goepfert joined a research cruise in the Arabian Sea last fall aboard the Indian research vessel Sagar Kanya to measure trace levels of iron and copper in the ocean. Copper catalyzes chemical reactions used by marine microbes to live and grow. These reactions break down nitrates in the ocean and release nitrous oxide, a greenhouse gas, into the air. The expedition provided evidence that copper can play a key role in limiting both marine life growth and global warming.

Dynamic duo

East Pacific Rise—The slopes of Pito Deep, a seafloor chasm west of Easter Island, expose the stacked layers of Earth's crust in a way that affords geologists a rare look at the effects of millions of years of volcanic eruptions. To compile detailed maps and images of this geologic growth chart, scientists on R/V *Atlantis* put a high-tech tag team to work. They deployed the tethered vehicle *Jason* for robotic studies, while sending the *Alvin* submersible and its three-person crew down for a first-hand human perspective.

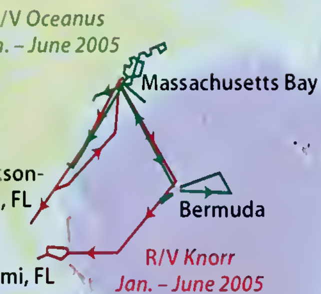
Gary Chiljean, WHOI

Tom Kleindinst, WHOI

Bay watch

MASSACHUSETTS BAY—After Boston Harbor was declared one of America's dirtiest waterways in the 1980s, Massachusetts extended an outfall pipe to carry sewage farther offshore. To monitor the waste's effect on the bay, the environmental management firm Battelle leased WHOI's coastal research vessel *Tioga* to measure water quality and chemical contaminants. Battelle officials said the year-old, 65-foot vessel is comfortable for work in high seas, and they will likely use *Tioga* again.

Peter Clift, WHOI



River dance

INDUS DELTA, PAKISTAN—WHOI geologists Peter Clift and Liviu Giosan have been exploring sandy outcrops and dunes in the Indus River Delta in search of ancient riverbeds. The tracings of buried waterways reveal how the coastal region has changed over the centuries. Dams and irrigation projects have depleted the great river's flow, fundamentally changing the mix of river and ocean sediments and the balance of salty and fresh water in its channels. The scientists also seek sedimentary clues to how the famous Southeast Asian monsoon began millions of years ago.

• Indus Delta, Pakistan

Diamonds in the rough

SOUTH AFRICA—WHOI geologist Rob Evans and colleagues from three continents are exploring some of the oldest rocks on the planet. The team has been crossing southern Africa to examine the Kaapvaal craton—continental rock that formed at least 2 billion years ago and is home to famous diamond-rich kimberlite pipes. The researchers are using magnetic and electrical surveying equipment to peer 300 kilometers (186 miles) into the deep structure of Earth's crust and lithosphere to learn how it formed and why diamonds are often found in these old regions.

• South Africa

• Bahia Honda, Panama

Core mission

JACKSONVILLE, FLA.—Pulling ancient mud from the seafloor requires a long reach. In February, the WHOI-operated R/V *Knorr* was raised into dry dock for eight weeks to install 34,000 kilograms (75,000 pounds) of new decking and steel components. It was the first in a series of changes to the vessel to accommodate a 45-meter (150-foot) sediment corer, the longest of its kind in the U.S. When fully installed in 2006, the new long corer will function like a giant seafloor probe, extracting sediments that reveal the history of climate and ocean circulation changes.

Jim Broda, WHOI

Under the ice

PALMER STATION, ANTARCTICA—WHOI biologist Scott Gallager spent six weeks at Palmer Station this spring, surveying and selecting offshore locations to deploy the Polar Remote Interactive Marine Observatory. PRIMO, scheduled for installation in late 2005, will be the first cabled observatory moored under Antarctic ice. It will monitor the ecosystem for a year, measuring water properties, recording images and sounds of nearby animals, and transmitting data via cable and satellite to scientists worldwide. Read more at oceanusmag.whoi.edu.

• Palmer Station, Antarctica

Scott Gallager, WHOI

Building a tsunami warning network

The Indian Ocean tsunami killed more than 200,000 people, including 45,000 in the town of Meulaboh, Indonesia, where the wave destroyed a vital port and swept hundreds of fishing boats inland. Mercy Corps, the international disaster relief agency, has asked WHOI scientists for help in restoring the port (see page 24).

DigitalGlobe

◄ Swirling waters recede offshore shortly after the first series of tsunami waves struck the shoreline in Kalutara on the southwestern coast of Sri Lanka on Dec. 26, 2004.

Scientists debate how to do the right thing—and do the thing right

Since the great Indonesian earthquake and tsunami of Dec. 26, 2004, policymakers and scientists around the globe have been embracing a rare moment of public attention on the oceans, accelerating plans to create a tsunami warning network and to prepare citizens for the next massive wave. Another potent earthquake along the same fault on March 28, 2005, has increased that sense of urgency.

The Bush administration has proposed spending $37.5 million over two years to greatly expand the nation's tsunami monitoring network by 2007. Internationally, the Indian, Australian, and Japanese governments have proposed systems for the Indian Ocean, as have the Germans, who also propose networks for the Mediterranean Sea and North Atlantic.

But in the rush to set up networks, some scientists are raising questions, seeking to prevent a noble idea from being an uncoordinated, feel-good gesture that is at best inefficient, and perhaps ineffective. The questions include:

- Will there be enough funds to build the network and to maintain it in the future?
- Will funds for the proposed networks be in addition to, or merely redirected from, scarce funding for ocean science?
- Can network efforts be coordinated with international partners and other global scientific efforts to maximize their benefits and mitigate their costs?
- What is the use of getting warnings from the sea if no infrastructure exists to convey them adequately to people on shore?

The U.S. initiative, led by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS), would deploy 32 new buoys equipped with instruments to detect the pressure of a tsunami wave in deep-ocean water (see map on page 18). Seven buoys would be moored in the Caribbean Sea and western Atlantic Ocean, with 29 more spread around the Pacific Rim, including four that are already operating.

The system also would include 40 gauges for sea level and tides, upgrades to 20 ocean-bottom seismometers, and funding for communications systems, risk assessment, computer modeling and prediction, education programs, and emergency preparedness.

The program does not provide much, if any, funding for ocean scientists outside of NOAA or USGS.

Internationally, the Comprehensive Test Ban Treaty Organization (CTBTO) is in the process of setting up 320 seismic monitoring stations around the world (175 are already working, including eight in Indonesia, Thailand, and Sri Lanka). Scientists and tsunami monitors currently rely on this Global Seismic Network to detect the location and depth of earthquakes—a small fraction of which may spawn tsunamis.

But the CTBTO system was designed for reconnaissance, not to disseminate emergency warnings. In March 2005, the organization began making plans to provide real-time data from selected stations, on a test basis, to tsunami warning centers and national data centers.

The expanded U.S. tsunami network would be a key first piece in the Global Earth Observation System of Systems (GEOSS), a 60-nation program to coordinate studies of Earth systems that NOAA Administrator Conrad Lautenbacher has been promoting. Proposed several years ago, GEOSS has been stalled in hard budget times, but the tsunami network has provided motivation to get the program off the ground.

"The world's attention has been focused on the vulnerability of people who live on the edge of the ocean, and we have a responsibility to respond to their need," said John Marburger, science adviser to President George W. Bush, during a January news conference.

The proposed $37.5 million for the U.S. tsunami monitoring program does not necessarily mean new money for science.

The current plan calls for the program to start in 2005 in order to be completed by the summer of 2007. To accomplish that, NOAA and USGS requested and received $25.4 million as part of an $82 billion emergency spending bill passed by Congress in May for military operations in Iraq and Afghanistan.

NOAA has requested $9.5 million for the tsunami program in the agency's 2006 fiscal year (FY06), which begins Oct. 1, 2005; USGS requested $5.4 million. Not incidentally, the NOAA research budget is scheduled to be cut by 6.7 percent in FY06; USGS will lose 4.6 percent.

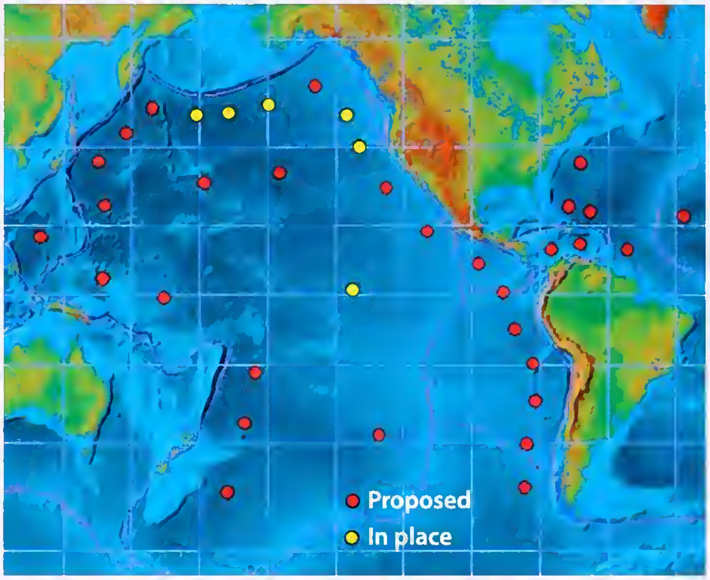
Even if NOAA and USGS receive the $37.5 million, that will put only 20 of the 32 buoys in the ocean. Deploying the other 12 will require additional funding in 2007.

"If there is no new money, they will have to take the funds for the hardware and ship time out of existing ocean funds," said WHOI Senior Scientist Robert Weller, a physical oceanographer and director of the NOAA-sponsored Cooperative Institute for Climate and Ocean Research. "This will, at a time of very tight funds, most likely severely damage one or more other programs."

The crucial issue, as ocean scientists see it, is sustaining the system once it is installed. Estimates range from $5 million to $12 million per year—or 10 times the $37.5 million startup costs—to maintain the buoy and seismometer network and for staffing the operations centers and research and education programs to make the network useful.

"The administration's proposed tsunami warning system would deploy many single-purpose buoys," John Orcutt, deputy director of Scripps Institution of Oceanography and president of the American Geophysical Union, said in testimony to the Science Committee of the U.S. House of Representatives in January. "Major tsunami events occur at time scales from decades to centuries, and even in the Pacific, tsunamis don't occur often. Between major tsunamis, the NOAA Pacific Tsunami Warning Center in Hawaii has a hard time maintaining its budget and personnel."

"We can think of solutions to the tsunami problem, but we have to decide if they are worth the cost," added Robert Detrick, a marine geologist and vice president for marine operations at WHOI. "Does society have the willpower to pay for these observations over decades or centuries? If we build a platform that allows other research to be conducted, we will give the system value even if a tsunami never occurs."



▲ The tsunami-monitoring network proposed by the U.S. includes 36 buoys in the Pacific and Atlantic Oceans. Four are already operating.

For instance, tsunamis could be just one of several natural hazards and phenomena monitored by a more well-rounded observing system. Such a system would simultaneously address several societal needs and scientific concerns—El Niño, earthquakes, ocean circulation changes, chemistry, ocean life—so that even if there is not a tsunami for a hundred years, the observation program could collect other critical data.

"This event is another indication of the pressing need for ocean observations on a global scale," said Weller. "We should be moving toward a long-term, ocean-observing strategy. We should take this opportunity and accelerate a multiagency, multipurpose program to get global real-time ocean observations for diverse societal benefit."

The Ocean Observatories Initiative led by the National Science Foundation includes an array of deep-ocean buoys that serve a variety of research endeavors—including bottom pressure gauges and seafloor seismometers—with instruments strung from the sea surface to the ocean floor. That program also includes cabled seafloor observatories, robotic vehicles, and drifting observatories.

David Green, leader of planning and integration for the NOAA program, said the agency has been told to design a tsunami-specific network, and while it is "planning for expanded capability—a platform for future sensors—we are not building that in right now."

"Is a tsunami network a real help for society?" Weller asked. "You can have warning buoys, but if there is not the shoreside infrastructure, training, and education to make use of the warnings, what good has been accomplished?"

WHOI Senior Scientist Alan Chave recalls growing up in Honolulu, where there are sirens and regular tsunami drills to keep the population prepared for the inevitable. "How do we get the word out to the people whose lives we want to save?" Chave said. "It could be difficult in countries with so little infrastructure. We need to be clever."

At the January Science Committee hearing, Chairman Sherwood Boehlert, a Republican from New York, criticized the Bush administration's $1.5 million proposal for tsunami education and outreach, calling it "tip money in this town."

"We need an education and awareness campaign, including emergency planning, drills, and training," said Laura Kong, director of the International Tsunami Information Center (see page 23). "The challenge in the South Pacific, for instance, is that there are many small islands and poor countries with very little infrastructure."

—Mike Carlowicz

Tsunamis in the Caribbean?

It's Possible

Two days before the devastating tsunami in the Indian Ocean on Dec. 26, 2004, two Woods Hole geologists reported that similar earthquake- and tsunami-generating conditions exist in the Caribbean Sea.

The Indian Ocean tsunami was caused by a magnitude 9.3 undersea earthquake in a deep-ocean trench off the Indonesian island of Sumatra, where two of Earth's crustal plates collide. Another earthquake, with a magnitude of 8.7, occurred March 28, 2005, along the same trench, about 120 miles to the south.

Just like Sumatra, the islands of Puerto Rico, the Virgin Islands, and Hispaniola are located near earthquake-prone deep-ocean trenches. A large fault on Hispaniola bears a striking resemblance to a fault on Sumatra.

In a study published Dec. 24, 2004, in the *Journal of Geophysical Research*, geologists Uri ten Brink and Jian Lin reported a heightened earthquake risk from the Septentrional Fault Zone, which cuts through the highly populated Cibao valley in the Dominican Republic. The potential for earthquakes of magnitude 7.5 or greater in the trenches offshore Puerto Rico and Hispaniola pose additional risk.

While tsunamis are rare in the Caribbean, earthquakes are not. More than a dozen earthquakes of magnitude 7.0 or greater have occurred near Puerto Rico, the Virgin Islands, and Hispaniola in the past 500 years. Several have generated tsunamis, the most recent in 1946 following a magnitude 8.1 earthquake off the northeast coast of the Dominican Republic, which killed more than 1,600 people.

With nearly 20 million people now living in that tourist region and a major earthquake occurring about every 50 years, Lin and ten Brink say it is not a question of if another major earthquake will happen, but when.

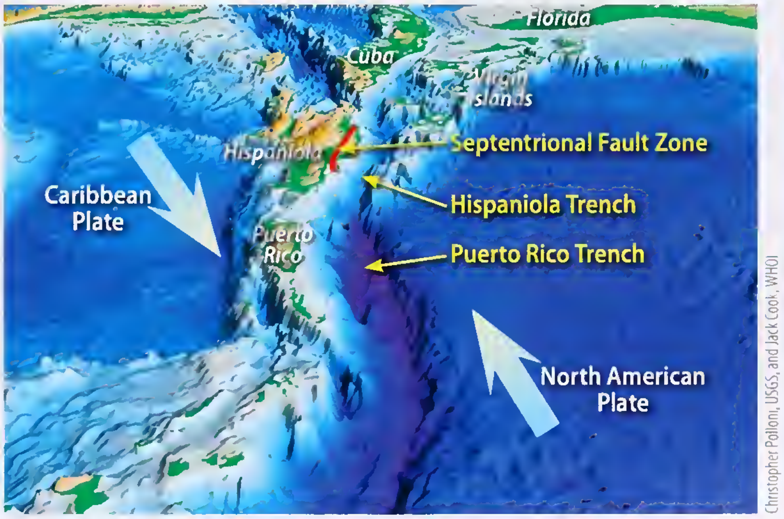
The risks of major earthquakes in the Caribbean, and the possibility of a resulting tsunami, although small, are real and should be taken seriously, said Lin, a senior scientist in the Geology and Geophysics Department at Woods Hole Oceanographic Institution, and ten Brink, a geologist at the U.S. Geological Survey in Woods Hole and an adjunct scientist at WHOI.

Earthquakes typically occur near faults, or fractures, in Earth's crust where rock formations—driven by the movements of the tectonic plates that make up Earth's surface—grind slowly past each other or collide. Stress builds up, and at some point, when stress overcomes friction, the rocks slip suddenly, releasing seismic energy in the form of an earthquake. That alleviates stress in one area, but increases it elsewhere along the fault line.

Most of these faults lie on the seafloor, so 80 percent of earthquakes occur in the ocean. Occasionally, the sudden rupture and movement of the crust can displace thousands of meters of water, setting in motion great tsunami waves.

Hispaniola, Puerto Rico, and the Virgin Islands sit atop small crustal blocks that are sandwiched between the Caribbean Plate and the North American Plate. The latter plate is being thrust down and under the Caribbean Plate to create a deep-ocean trench, called a subduction zone.

The Puerto Rico Trench is about 900 kilometers (560 miles) long and 100 kilometers (60 miles) wide. It runs roughly parallel



▲ Puerto Rico, the Virgin Islands, and Hispaniola (shared by Haiti and the Dominican Republic) are near earthquake-prone deep-ocean trenches similar to those that caused earthquakes and a tsunami off Sumatra. Deep-ocean trenches occur where two of Earth's crustal plates collide, with one thrusting beneath the other. The Septentrional Fault Zone in Hispaniola also bears striking resemblance to a large fault that runs along Sumatra.

to the northern coast of Puerto Rico, about 75 miles offshore. It is the deepest point in the Atlantic Ocean, descending 8,340 meters (27,362 feet) below the sea surface. The Hispaniola Trench, which parallels the north coast of the Dominican Republic and Haiti, is 550 kilometers (344 miles) long and 4,500 meters (14,764 feet) deep.

Ten Brink and Lin studied historical earthquake data and the geology of the northern Caribbean Plate boundary, and then used three-dimensional models to calculate the stress changes in and near the trenches after each earthquake.

Lin said that each time an earthquake occurs on the Puerto Rico and Hispaniola Trenches, it adds stress to the Septentrional Fault Zone on Hispaniola.

The region has a long history of destructive earthquakes. Major earthquakes have damaged Puerto Rico and the Virgin Islands 13 times since 1670, with two of the events accompanied by destructive tsunamis.

"Our results indicate that great subduction-zone earthquakes, which often occur in the deep trenches offshore, have the potential to add stress or trigger earthquakes on other faults on the nearby islands," Lin said.

The Puerto Rico and Hispaniola Trenches are not the only tsunami threats on the Atlantic coast of the Americas. In 1755, an earthquake in an undersea fracture zone off Portugal generated a giant tsunami that reached as far as the Caribbean region. It killed more than 100,000 people, destroyed the city of Lisbon, undermined Portugal as a rising European power, and had a profound impact on the philosophical and religious thinking of the era.

Tsunamis can also be generated by submarine landslides, ten Brink noted. In 1998, a magnitude 7.1 earthquake occurred 24 kilometers (15 miles) offshore Papua New Guinea. It was not large enough to generate a tsunami directly, but it caused an undersea landslide that caused a tsunami 15 meters (50 feet) high, which killed some 2,200 people.

"We don't want people to overreact," said Lin. "We just want to make them aware of the potential risk. It is similar to understanding hurricanes or tornadoes and being prepared to react when one is coming."

—*Shelley Dawicki*

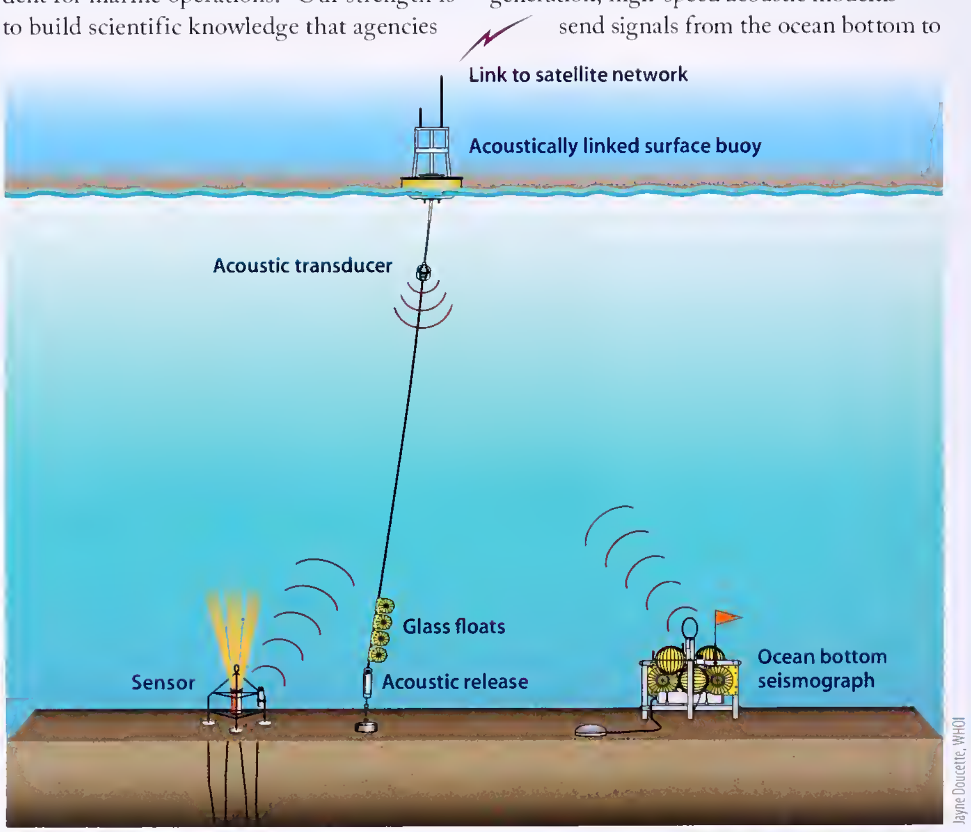
What could a tsunami warning network look like in the future?

WHOI engineers develop innovative technology for ocean monitoring

The five-year-old Deep-ocean Assessment and Reporting of Tsunamis (DART) buoy system, operated by the National Oceanic and Atmospheric Administration (NOAA), is battle-tested and operational and can address the immediate need for a tsunami warning network. Researchers at Woods Hole Oceanographic Institution are concentrating on the next generation of ocean observing platforms.

"WHOI's role is to build new sensors and develop technology," said Robert Detrick, WHOI senior scientist and vice president for marine operations. "Our strength is to build scientific knowledge that agencies like NOAA and society can profit from. That's what we do—we build the better mousetrap, the cheaper, more sustainable way of making observations."

Researchers from WHOI—including Detrick, Dan Frye, Lee Freitag, and John Collins—the Scripps Institution of Oceanography, and the University of Washington have been working to see if they can use advances in buoy, satellite, and acoustic technology to develop mini-observatories for several ocean studies from one mooring string. A suite of meteorological sensors adorns their surface buoy; a current meter may hang in mid-water on the mooring string; and an ocean-bottom seismometer and two nodes (for plugging in other instrument packages) rest at the seafloor. Next-generation, high-speed acoustic modems send signals from the ocean bottom to



▲ WHOI engineers are developing moored buoy systems to transmit data acoustically from seafloor instruments to surface buoys in near-real-time. The buoy transmits data and commands via satellite between shore-based labs and the observatory.

the buoy and more from the surface back to the bottom instruments. Transmitters on the surface buoy relay data and commands between shore-based labs and the observatory via the Iridium satellite network.

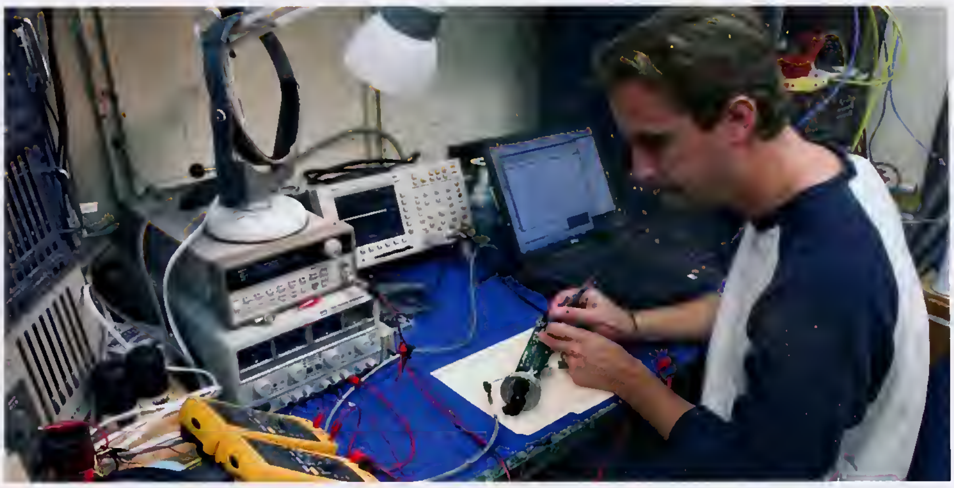
In May 2004, the team deployed its buoy in Nootka Bay, off Vancouver, British Columbia, for a year of data gathering. The scientists have transferred up to 1 megabyte of data per day from the observatory, "pinging" the system four to six times daily for low-resolution data—for the broad overview of activity—and asking for more detailed data sets when an event occurs.

"Survivability is a big problem with buoys, particularly in coastal waters," said Frye. "Winds, waves, and currents abuse moorings, so you need a lot of compliance in the lines. But slack mooring lines cause their own problems." The solution? Frye and his WHOI colleagues affectionately call it the "Gumby" moor—because it uses ultra-stretchy rubber hoses, reinforced with nylon, that can stretch to twice their usual length.

In February 2005, Frye and colleagues began sea trials of the new mooring system to allow scientists to collect real-time seismic data in nearshore waters. The Gumby moor's flexible hoses have electrical conducting wires embedded in their walls, making it possible to transmit continuous, high-rate, real-time data from the seafloor to shore. The system also allows power generated by solar panels on the surface mooring to flow to the bottom instruments.

Instead of a satellite link, the buoy communicates with shore stations via short-range radio signals. A Global Positioning System receiver on the surface buoy allows the instruments to keep accurate, synchronized time, removing a data processing step and speeding the transfer of crucial information into the global seismic network.

If tests go well, Frye and colleagues plan to deploy the first Gumby mooring off the Caribbean island of Grenada in 2006. That mooring would include an ocean-bottom seismometer and other instruments to detect the flow of magma and other activity in an underwater volcano near the island. Just as scientists monitor activity of Mount St. Helens to predict the next eruption, researchers hope to sense activity in the undersea volcano before it erupts and sends a tsunami toward the island.



Photos by Tom Kleindinst, WHOI

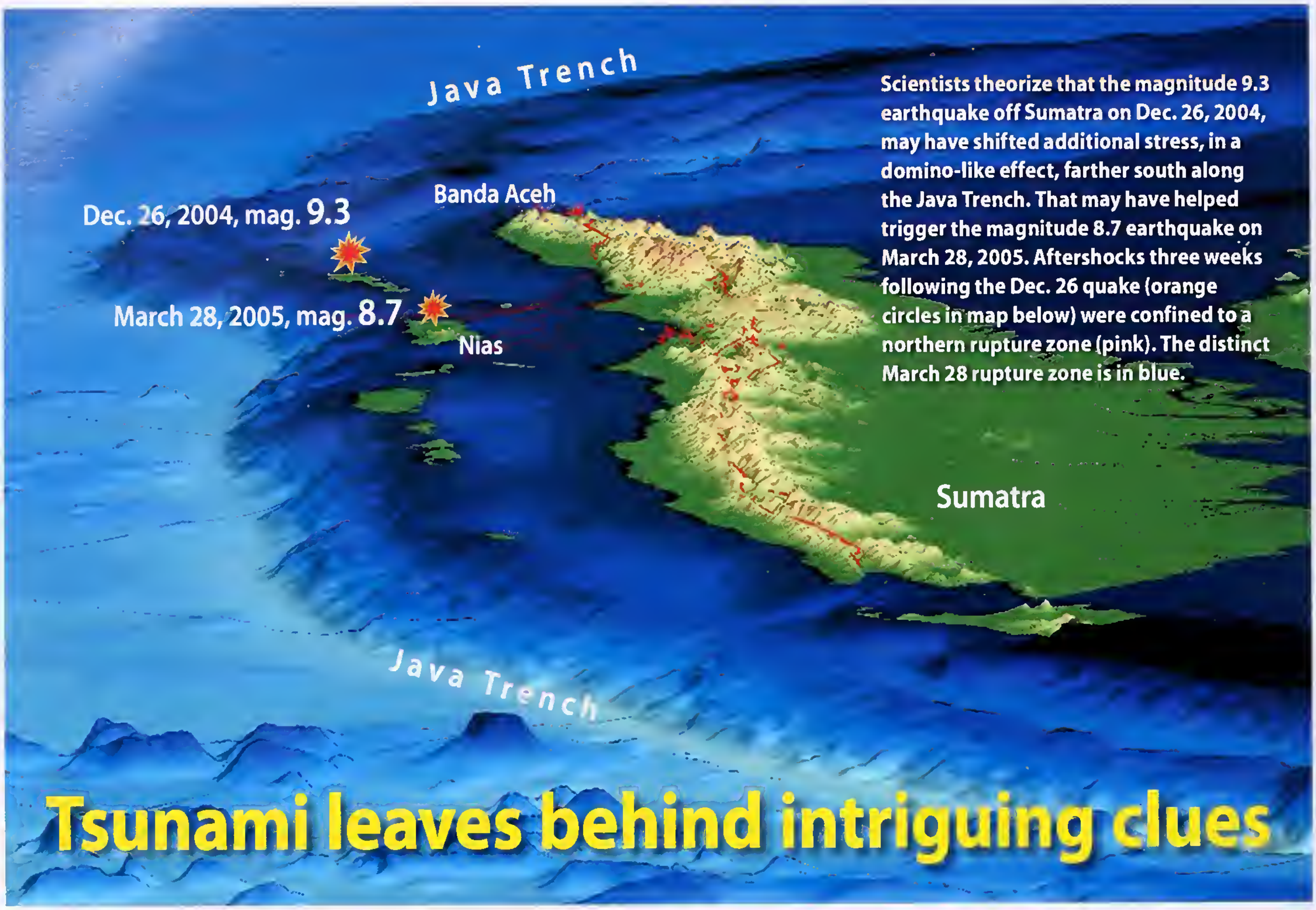
Next-generation ocean-monitoring technology being developed by WHOI researchers may be incorporated into future tsunami warning systems. Above, engineer Keenan Ball tests a high-speed acoustic modem to send data between seafloor instruments and surface buoys. At left, seismologist John Collins (foreground) and geologist Beecher Wooding examine an ocean-bottom seismometer that records undersea earthquakes. Below, engineer Lee Freitag is working on acoustic communications systems for ocean observatories.

Senior Scientist Alan Chave is working with colleagues from the University of Washington and Scripps Institution of Oceanography to create the "cyber infrastructure" for future cabled seafloor observatories. In a $3.9 million pilot project called Laboratory for the Ocean Observatory Knowledge Integration Grid (LOOKING), the team will develop fiber-optic and wireless networks, Web-like services, information protocols, and hardware that will be the backbone for the seafloor observatory movement in ocean science.

"The ability to have instruments on the seafloor communicate with users on shore automatically and seamlessly is critical to the success of ocean observatories," said Chave. "LOOKING will help us develop and implement those observatory networks."

—*Mike Carlowicz*

These projects were funded by the National Science Foundation, the Office of Naval Research, the U.S. Geological Survey, and the W.M. Keck Foundation.



Scientists theorize that the magnitude 9.3 earthquake off Sumatra on Dec. 26, 2004, may have shifted additional stress, in a domino-like effect, farther south along the Java Trench. That may have helped trigger the magnitude 8.7 earthquake on March 28, 2005. Aftershocks three weeks following the Dec. 26 quake (orange circles in map below) were confined to a northern rupture zone (pink). The distinct March 28 rupture zone is in blue.

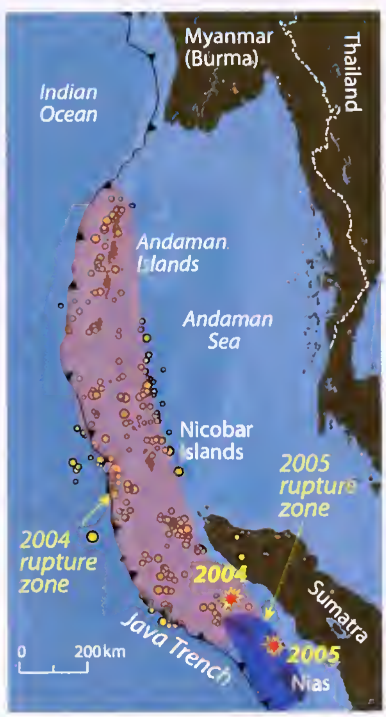
Kerry Sieh, California Institute of Technology

Tsunami leaves behind intriguing clues

Is a domino effect operating along faults in the Indian Ocean?

If any good has come from the devastating earthquakes off Sumatra, it is that they are providing scientists with unprecedented clues to learn how large undersea earthquakes occur and how they create tsunamis.

In the wake of the catastrophic earthquake and tsunami on Dec. 26, 2004, and a subsequent magnitude 8.7 quake on March 28, 2005, scientists have gathered new information to answer provocative questions: Did the Dec. 26 earthquake shift stress in the Java Trench where the earthquakes occurred and help trigger the March 28 quake? Was the Dec. 26 quake shallow, and did this contribute to generating such a great tsunami? Why did the March 28



Data provided by USGS. Illustration: Jack Cook, WHOI Graphic Services and, Jian Lin, WHOI

quake generate only a minor tsunami even though it was a great quake?

The earthquakes occurred in a subduction zone where two of Earth's great crustal plates are colliding. As one plate is thrust beneath another to form the deep Java Trench, it causes the buildup of stress in rock formations, which slip suddenly to generate earthquakes.

Jian Lin, a marine geophysicist at Woods Hole Oceanographic Institution, and his colleague Ross Stein of the U.S. Geological Survey in Menlo Park, Calif., have investigated thrust earthquakes both on land and under the oceans for several years. In a study published in early 2004, the two scientists theorized that as thrust earthquakes alleviate stress in one region, they can shift that stress to adjacent areas.

In a domino-like effect, stress can transfer through the crust to interact with neighboring faults and trigger another earthquake

elsewhere. Lin and Stein noted that such a domino-like reaction appears to have occurred in a series of moderate-sized thrust quakes in central California in the 1980s.

Is the domino-like reaction also occurring in the Java Trench? Recently several research groups calculated that the Dec. 26 quake shifted additional stress farther south along the Java Trench. That could have helped trigger the March 28 earthquake, which occurred about 190 kilometers (120 miles) southeast of the December quake.

"If this is true, this could be good news for the people living close to a large part of the Java Trench where the stress was released by the recent great quakes," Lin said. But unfortunately both quakes have now added stress to other fault lines in this region, making them more susceptible to future quakes.

With an estimated magnitude as high as 9.3, the Dec. 26 earthquake could be the second largest ever recorded. The largest earthquake ever recorded was a magnitude 9.5 event in a geologically similar ocean trench off Chile in South America in 1960, which killed an estimated 2,000 people.

Lin found a striking comparison between the 1960 and 2004 earthquakes: Both ruptured the seafloor for distances as long as 1,000 to 1,300 kilometers (625 to 810 miles), and both caused ocean-spanning tsunamis. However, the rupture plane of the 2004 quake appears to be significantly shallower and narrower in its down-dip direction, resembling a long, "skinny" stripe.

"What we learn from the Dec. 26 event will probably define what we know about tsunami-generating earthquakes for a long time," said Lin, who plans to survey the rupture zone on the Java Trench this fall on a research cruise with an international team of colleagues. "The new observations should help us to improve earthquake models and bring us closer to understanding the behavior of these devastating events."

But there are still many unsolved mysteries of the Dec. 26 and March 28 events, including why the March 28 quake created only a minor tsunami.

"It is clear that a tsunami early warning system in the Indian Ocean is badly needed," Lin said.

—*Shelley Dawicki*

Tsunami central

MIT/WHOI graduate leads the world's tsunami awareness program

Laura Kong got the first phone call shortly after 3 p.m. on Christmas Day 2004. Colleagues from the Pacific Tsunami Warning Center (PTWC) informed her that a magnitude 8 earthquake had occurred somewhere in the eastern Indian Ocean. It is standard procedure for the team to call Kong—director of the International Tsunami Information Center (ITIC) in Honolulu, Hawaii—whenever there is a quake of magnitude 6.5 or larger.

An hour later, she got a call from Charles McCreery, director of PTWC. The earthquake was much larger and big enough to raise concerns about a tsunami. But without tsunami-monitoring instruments in the Indian Ocean, they couldn't know for sure. Staff at the center had tried to inform their Indonesian colleagues without success.

"The center had a reading that suggested a tsunami was possible," said Kong. "But there were no protocols for efficient delivery of the message. In that part of the world, there is almost no infrastructure for assessing the local risk, deciding how to react, and getting people out of the way."

Kong, a 1990 graduate of the MIT/WHOI Joint Program in Oceanography/Applied Ocean Science and Engineering, was one of the first people in the world to learn the magnitude of the earthquake off the coast of Indonesia. But she had to wait, like the rest of us, to know the full scale of the catastrophic tsunami. She got the news from a Reuters news report about four hours after the first phone call.

Kong became director of ITIC in 2001, after spending her post-WHOI years working in operations at the tsunami warning center and conducting research at the University of Hawaii, the U.S. Geological Survey, and the University of Tokyo's Earthquake Research Institute. She studied marine seismology in the 1980s with then-WHOI and MIT scientists Michael Purdy and Sean Solomon.

As director of ITIC, Kong's job is a blend of administrator, scientist, diplomat, and teacher. She administers the activities of the 26-nation International Coordina-

▼ Laura Kong (foreground, right), director of the International Tsunami Information Center, discusses tsunamis and provides safety information to visitors at an ocean fair at the Bishop Museum in Honolulu.

Courtesy of Laura Kong

tion Group for the Tsunami Warning System in the Pacific. She promotes technology transfer and tsunami and seismic data sharing among agencies and nations, while recommending improvements to the warning system. Her group also serves as a clearinghouse for tsunami information and educational materials.

Kong participates in the U.S. National Tsunami Hazard Mitigation Program, but her principal allegiance is to the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific, and Cultural Organization (UNESCO). ITIC was established in 1965 following the 1960 Chile tsunami and the 1964 Alaska tsunami, the last to strike the U.S. mainland.

Since world leaders began declaring that nations must take steps to avoid another catastrophe like the Dec. 26 Sumatra tsunami, Kong and her staff have been hunkered down. They are trying to capitalize on their Pacific Ocean experiences to help establish and implement a proposed Indian Ocean network. UNESCO and its emissaries such as Kong have been busy organizing meetings to unify and coordinate the global response to tsunami hazards.

The first meeting, held in March at UNESCO Headquarters in Paris, convened 270 experts from 45 countries to share technical information and to plan implementation of the Indian Ocean Tsunami Warning System. A second meeting in April in Mauritius brought together high-level government officials and donors to discuss funding and to agree on a work plan.

Since the Dec. 26 tsunami, the traffic in Kong's e-mail box has risen from 10 messages per day to hundreds, with inquiries and information from students, journalists, concerned citizens, and officials from around the world. ITIC maintains an e-mail listserv for scientists and tsunami monitoring specialists; in the first month after Dec. 26, it collected nearly 400 postings from scientists sharing data, computer models, and other observations.

"We are trying to lead by example for the whole world," said Kong. "We're trying to help governments understand what a tsunami warning system is, what it isn't, and what's involved in setting one up."

—*Mike Carlowicz*

Paul Dudley Hart, Mercy Corps

◄ WHOI coastal geologist Rob Evans (right) and Kresno Wiyoso of Mercy Corps, an international disaster relief organization, survey the destruction wrought by the Dec. 26 tsunami in the Indonesian town of Meulaboh.

Agency enlists WHOI scientists to help restore a devastated port

The Indian Ocean tsunami created a flood of challenges for international disaster relief and development organizations such as Mercy Corps. Consider the devastation in just one place, Meulaboh, an Indonesian coastal fishing town.

The tsunami killed an estimated 45,000 people there, about 15 percent of the population. It ruined most buildings in the town's port, overran inland rice paddies with sediments and salt water, and uprooted many key crop-bearing trees or drowned them with salt water. It washed away substantial shoreline regions, totally altered an estuary through which fishing boats access the sea from an upriver port, and destroyed a large portion of a sandbar at a river mouth.

"Meulaboh's lifeblood—its port—has disappeared as an operating entity," said Paul Dudley Hart, director-at-large for Mercy Corps. "We are now hauling and repairing boats swept inland, often by well more than a kilometer, and may soon start building new ones, but until they have a functioning port to come home to, the fleet has limited purpose. If we can help get the port rolling, we could play an enormously important role in resurrecting the fishing industry and all its ancillary enterprises—chandlers, ice factories, net-makers, markets."

A key to rebuilding the port is exploring changes to the seafloor and shoreline. "We needed to inform our relief and redevelopment decisions with sound science," Hart said. "To approach the disaster without benefit of scientific insight seemed illogical—hence our approach to WHOI."

Hart was director of development at Woods Hole Oceanographic Institution in the 1990s and thus was familiar with the expertise that WHOI could bring to the situation. From April 22 to May 7, 2005, he and WHOI geophysicist Rob Evans journeyed to Indonesia, meeting with government officials and traveling to Meulaboh.

"We left impressed by the level of planning and commitment within the Indonesian government in the face of overwhelming challenges, and we were in awe of the energy and lack of self-pity with which the people of Meulaboh are rebuilding shattered lives," Hart said. "We also left excited about the receptivity of Indonesian officials and scientists to the prospect of enlisting WHOI and Mercy Corps to help to reestablish the port of Meulaboh."

In the near term, Evans said, WHOI scientists could provide and interpret the bathymetric data needed to restore the estuary and port. The same data will provide key details that will help reveal the tsunami's impact on the shoreline. Over the longer term, the tsunami provides an unprecedented opportunity to study how shoreline, river systems, and marine ecosystems recover over time from natural phenomena that effectively wipe the slate clean.

"We're in the first chapter of a very dynamic situation," Hart said, "and having WHOI looking over our shoulders to see how the system is responding is invaluable."

—*Lonny Lippsett*

Steve Earley, The Virginian-Pilot

Photos by Tom Kleindinst, WHOI

1
This True's beaked whale, which died on a Virginia beach, provided blubber for WHOI researchers to study the accumulation of flame retardants in marine mammals.

2
WHOI chemist Emma Teuten displays some of the 10 kilograms (22 pounds) of whale blubber used for the study.

3
She dulled a few dozen knives cutting the blubber into strips and cubes so that they could be puréed in a blender.

Scientific detective work tracks chemicals to a surprising source

Telltale clues reveal a chemical found in whale blubber is natural, not industrial

Researchers at the Woods Hole Oceanographic Institution have found that two chemicals accumulating in the tissues of marine animals and suspected to be man-made pollutants actually came from natural sources.

Brominated organic chemicals are used as flame retardants for electronics, furniture, and textiles. In recent years, they have been found to be ubiquitous in the environment, and accumulating in fish, marine mammals, and human breast milk. Some researchers suspect that these compounds may affect animal and human health, and several compounds have been banned.

By isolating 1 milligram of methoxylated polybrominated diphenyl ethers (MeO-BDEs) from 10 kilograms (22 pounds) of whale blubber, Emma Teuten, a postdoctoral fellow in the Department of Marine Chemistry and Geochemistry, found that the MeO-BDEs in the blubber contained carbon-14 (^{14}C). This natural radioactive isotope of carbon is incorporated into all living things, but it would have long ago decayed out of petrochemicals used by industrial chemists. That means Teuten's suspect chemical was derived from a natural, though still unidentified, source.

The finding was published Feb. 11 in the journal *Science*. Associate Scientist Chris Reddy, a geochemist, and Research Associate Li Xu of the WHOI Geology and Geophysics Department were key contributors to the research.

"Previous studies had suggested that some brominated and chlorinated compounds accumulating in wildlife might be of natural origin," said Mark Hahn, a marine toxicologist in the WHOI Biology Department. "The difficulty in knowing for sure whether these compounds are produced naturally or by humans is that some anthropogenic compounds are also made naturally by some organisms, and some anthropogenic compounds can also be biologically or chemically transformed in the environment to derivatives that resemble natural products."

"Teuten and Reddy have provided the first definitive evidence that

4
Teuten tries to hold back large, grainy pieces of blubber while pouring her blended mixture into a beaker.

5
She pours concentrated sulfuric acid into a flask full of fat-rich whale extract, creating a viscous, black mixture.

6
Teuten washes the acid from the extract with hexane and water, then passes it through a silica gel (white column) to further purify the samples.

specific BDE derivatives are in fact naturally produced and can bioaccumulate to levels similar to those of some notorious contaminants," Hahn added. "They did this by combining an elegant analytical method—analysis of radiocarbon content—with the brute force purification of the compounds from large amounts of whale blubber."

It took 18 months, three blenders, and dozens of dulled knives to conduct this experiment.

Proving the origin of MeO-BDEs seems like a simple problem: Find ^{14}C in a sample, and you know that the chemicals came from Mother Nature, not a factory.

"In the laboratory, we call this approach the 'dead or alive theory,'" said Reddy. "Petrochemicals are radiocarbon-dead and natural products are radiocarbon-alive."

But to detect ^{14}C, chemists require a sizable sample. To find ^{14}C within the scarce molecules of brominated compounds required a ridiculously large sample.

The first challenge was acquiring a large piece of whale blubber. Reddy requested and received a permit from the National Marine Fisheries Service, which limits the "take" of marine mammals for research. Teuten then contacted researchers at various marine mammal stranding and rescue operations to alert them that they needed a sample the next time one was available.

"We call this approach the 'dead-or-alive' theory. Petrochemicals are radiocarbon-dead and natural products are radiocarbon-alive."

By the fall of 2003, the unfortunate beaching and death of a True's beaked whale in Virginia turned into good fortune for the WHOI research team. Teuten received a package from the Virginia Marine Science Museum containing 10 kilograms (22 pounds) of foul-smelling but scientifically precious whale flesh.

That's when the brute force portion of the experiment began. Teuten had to chop, cube, and blend mounds of whale blubber, a task made even less appealing by the fact that she is a vegetarian.

"It was messy, oily work, and I never thought working with blubber would be so nasty," Teuten said. She dulled many a knife and had to purchase three blenders before moving on to more traditional tools of chemistry, such as filtering, acid washes, dialysis techniques, and chromatography.

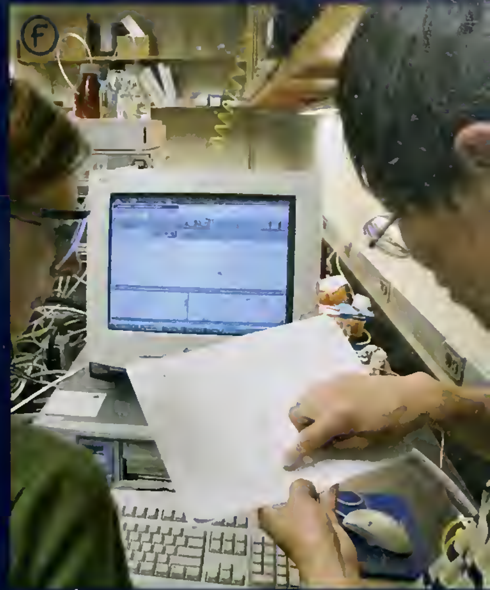
"What Emma did was heroic—like finding a needle in a haystack," said Reddy. "She removed 10,000,000 milligrams of whale material—mainly fats—to get our compounds of interest in very high purity."

"There was no road map for this," Teuten said. Most chemical extractions involve work with 50 grams; Teuten started with 200 times that in order to isolate just 1 milligram of the brominated compounds. "This kind of thing just hasn't been done much in radiocarbon analysis."

Teuten and Reddy finally submitted their sample of brominated

7
She uses a rotary evaporator to remove excess solvent.

8
Teuten displays a vial containing the desired extract of halogenated organic compounds—less than one percent of the initial sample.



9
Teuten (left) and Li Xu examine preliminary results from the gas chromatograph, which identifies individual chemical compounds in a sample.

compounds for analysis at the National Ocean Sciences Accelerator Mass Spectrometer facility (based at WHOI), where chromatography expert Li Xu became involved in the effort. They found ^{14}C.

"This radiocarbon technique is very exciting," said Gordon Gribble, an organic chemistry professor at Dartmouth College and a leader in the study of halogenated compounds naturally found in the environment. "There's been no other way to distinguish the origin of the same compounds that are produced both by nature and man."

In recent years, polybrominated diphenyl ethers (PBDEs) have been found in freshwater fish near industrialized areas of the Great Lakes and Northern Europe, though there are no known natural sources for these chemicals in fresh water. But natural PBDEs also have been found in sea sponges off Australia and in the dolphins living nearby.

Based on preliminary findings of possible health risks linked to PBDEs, the European Union and the state of California have banned certain formulations of flame retardants. Industrial producers counter that the compounds are non-reactive and do not degrade in the environment, and therefore are safe. But no one really knows for sure.

For decades, environmental groups have said that nature would never make brominated compounds or other halogenated chemicals, Gribble noted. But in recent years, these compounds have been found in forest fires, volcanic ash, soil, peat bogs, and myriad marine organisms.

"It appears that nature has been producing these chemicals since the first forest fire and since life on Earth began," he said. In the ocean, where many of these compounds are ubiquitous, organisms have developed ways of synthesizing these compounds from oceanic salt for use as natural pesticides and repellents.

"As we design environmental laws for the regulation of chemicals, we have to be aware of what nature is making," said Gribble. "We have to evaluate each chemical on a case-by-case basis."

"Many people have the simplistic idea that synthetic equals bad and natural equals good," said Hahn. "But the source of a compound does not determine its toxicity. Some of the most toxic chemicals we know of are natural products. Whether the natural BDE derivatives that Teuten and Reddy identified are affecting the health of the animals that accumulate them is an open question that needs to be addressed."

If natural products are bioaccumulating in the same manner as industrial compounds, Teuten noted, then some marine animals have been exposed to these natural chemicals for many years.

"The presence of natural analogs may help toxicologists explain how and why some animals have the ability to metabolize industrial compounds such as PCBs," said Teuten. If scientists can understand how animals metabolize natural brominated compounds, they might be able to better understand how animals process industrial compounds.

—Mike Carlowicz

The study was supported by the National Science Foundation, The Camille and Henry Dreyfus Foundation Inc., the J. Seward Johnson Fund, and the WHOI Ocean Life Institute.

"Alien vomit, that's what kids call it," said WHOI scientist Mary Carman about species of sea squirts that have invaded New England waters. "Anyone who likes to eat seafood should worry about this." As they grow, sea squirts envelop rocks (below) and living things on the seafloor.

Tom Kleindinst, WHOI

Little squirts, big trouble

Invasive species smothers everything in its path and poses threat to fisheries

Sandwich Town Beach was empty at low tide on a winter afternoon when scientist Mary Carman yanked on hip boots and waded among the eel grass and barnacles, her brown eyes scanning the clear water. Spotting a butter-colored mass on a rock, she rolled up her jacket sleeve and plunged in her bare hand. Out came something resembling soggy scrambled eggs.

"Alien vomit, that's what kids call it," Carman said. In fact, the cold, rubbery animal was a troublesome species of sea squirt that invaded the New England coast, probably from Asia or Europe, in the early 1990s.

Dann Blackwood, USGS

Lacking natural predators, sea squirts are now found along the coast from Connecticut to Maine. They are also overrunning offshore areas with valuable fisheries such as Georges Bank, where dense mats of sea squirts cover 100 square kilometers (40 square miles) of the seafloor.

In April, more than 100 marine biologists, coastal resource managers, and shellfish industry

► Like a creature from a horror movie, sea squirts cover rocks, vegetation, and shellfish.

Dann Blackwood, USGS

representatives from nine countries gathered for a conference at Woods Hole Oceanographic Institution to trade strategies to keep sea squirt populations in check.

"Nothing really wants to eat it. Nothing grows on it. And nothing seems to prevent it from spreading," said Dann Blackwood of the U.S. Geological Survey (USGS) in Woods Hole, who works with scientists photographing, videotaping, and mapping the spread of sea squirts on Cape Cod and New England.

While invasive sea squirts won't harm people, scientists worry about effects on marine life. Evidence shows that the sea squirts smother scallops and mussels, push out native species of sea squirts, and coat the seafloor, possibly making areas uninhabitable to fish eggs and shellfish larvae.

"Anyone who likes to eat seafood should worry about this," Carman said.

Scientists suspect the sea squirt hitched a ride in water used as ballast on cargo ships, or on imported shellfish used in the aquaculture industry. Like green crabs, kudzu, gypsy moths, and tens of thousands of other non-native animals, plants, insects, and microbes that have settled in the United States over the last several centuries, the sea squirts could have potential ecological and financial impacts.

Damages and control costs related to all invading species in the U.S. are estimated at $137 billion per year, according to a study by Cornell University ecologist David Pimentel. Costs associated with sea squirts are not yet known, but among the more notorious examples of damages caused by an invasive species are zebra mussels, which have spread to nearly two dozen states since the 1980s. They often outcompete and overwhelm native species, and they block water intake pipes. Repairs cost tens of millions of dollars per year.

Sea squirts are tunicates, a named derived from a firm, rubbery outer covering called a "tunic." Of the nine types of sea squirts found on Cape Cod, six are invasive species. Carman focuses her research on a species of the genus *Didemnum*, which forms dense mats made from many small, linked individuals.

The organisms suck water into one tube to ingest algae and bacteria and then shoot the water out a second tube. These bursts of water gave it the name "sea squirt."

At the tide pool in Sandwich, Mass., Carman showed how sea squirts kill. Wiggling her finger into a sea squirt's wrinkly folds, she pointed out shellfish engulfed within them. Like a creature from a horror movie, the sea squirt had spread up and around a rock, smothering everything in its path, including shellfish.

Carman initially encountered the animal seven summers ago as a naturalist teaching youth education programs on Cape Cod.

"It was difficult to avoid them," she said. "Tons of them were on the docks, on pilings, in tide pools, looking like dead brain tissue." In tide pools and rocky sea beds, they often form wide, lumpy mats. On docks, lines, and boat hulls, they grow pale, stringy strands, like multi-armed octopi.

Kids peppered her with questions about this odd creature, and she quickly learned that scientists had no ready answers. She began work in the Geology & Geophysics Department at WHOI and acquired funding from a cooperative grant between USGS and WHOI.

"What started as a hobby has turned into a full-fledged research project," said Carman, who has a degree in paleontology and previously studied microscopic invertebrate fossils at The Field Museum in Chicago. In December 2003, she began working on field studies with research geologist Page Valentine of the USGS in Woods Hole. At least once each month, they venture to the Sandwich Town Beach for research.

Their experiments include snipping sea squirts and moving portions to isolated, contained areas of the tide pool to see how they reproduce and grow (they do—and quickly—the scientists have learned). The scientists also observe whether predators feed on sea squirts (only periwinkle snails, and only if the sea squirts are dead).

"Invasive sea squirts do present a problem, but we're figuring out some things we could do," Valentine said. At Georges Bank, for example, possible strategies involve keeping fishing gear away from the sea squirts, to avoid dragging them to unaffected areas. Since sea squirts do not survive long when exposed to air, Valentine and Carman are studying how mussel and oyster farmers may be able to stymie sea squirt growth by drying out equipment that could host the organism.

At the international conference in April —sponsored in part by the WHOI Ocean Life Institute—attendees presented strategies that included vacuuming sea squirts from barges, wrapping ship hulls in plastic sheets, and even cooking the slimy creatures into seafood chowder.

"People in Korea, Chile, and elsewhere like to eat them, but tunicate researchers, who know the details of where tunicates live (tide pools and rocky sea beds) and what they eat (bacteria and algae), find it very difficult to partake," Carman said.

"I think the key thing we learned is that there is no magic answer," Carman said. "We need to unite a lot of smart people to figure out the next steps for dealing with this creature."

—Amy E. Nevala

Rapid response

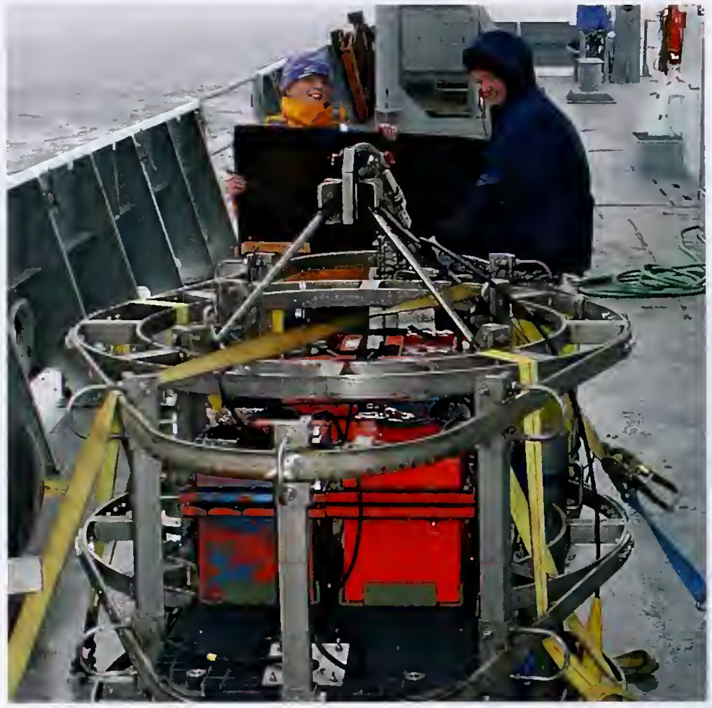
Researchers scramble for rare opportunity to catch an underwater volcanic eruption in action

The earthquakes were coming fast and frequent, as many as 50 to 70 an hour. On a Sunday morning, Feb. 28, undersea hydrophones began detecting the most intense swarm of earthquakes to occur in the last three years along the Juan de Fuca Ridge, about 320 kilometers (200 miles) off the Pacific Northwest coast.

Within 36 hours, signals from 1,498 earthquakes were relayed to onshore computers as scientists sent a flurry of e-mail messages to discuss the likelihood that a volcanic eruption was occurring on the bottom of the northeastern Pacific Ocean. By Tuesday, they were mobilizing researchers, shipping tons of research equipment overnight to Seattle, arranging to load a research vessel that happened to be docked nearby, and catching last-minute flights—all for the rare chance to witness an undersea volcanic eruption.

Such deep-ocean eruptions are not uncommon, happening dozens of times annually around the world. In fact, the eruptions are part of an ongoing, fundamental process that continually creates new seafloor crust. This crust spreads out from its volcanic sources to create new ocean basins and reshape Earth's face throughout the planet's history.

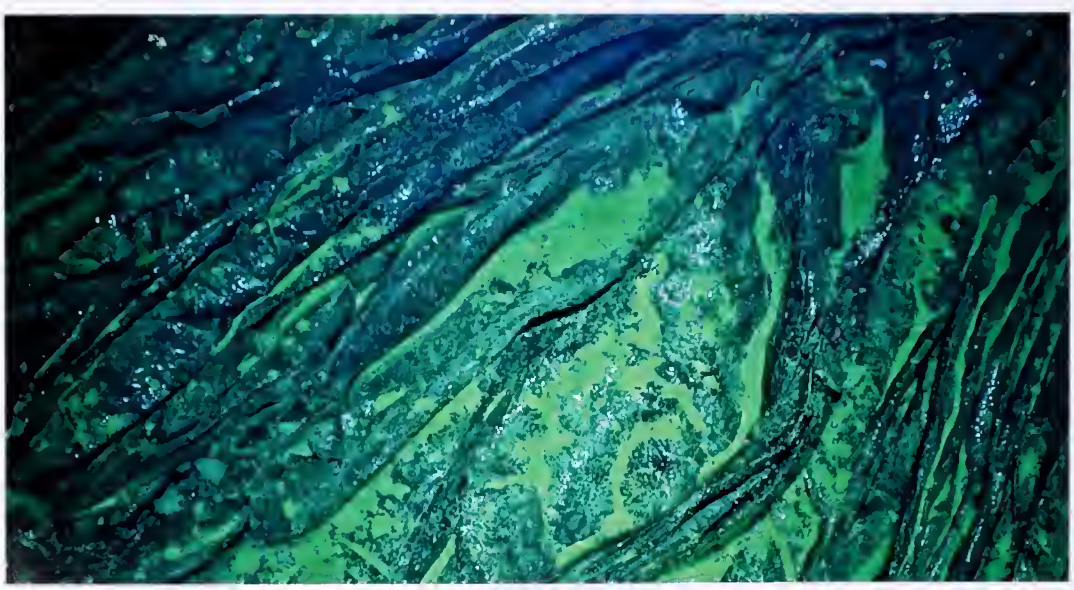
But the vast majority of those earthquakes and eruptions occur far out to sea, where there are no instruments to detect them. Even if they are detected, they are usually too far to reach quickly by ship.



Marshall Swartz, WHOI

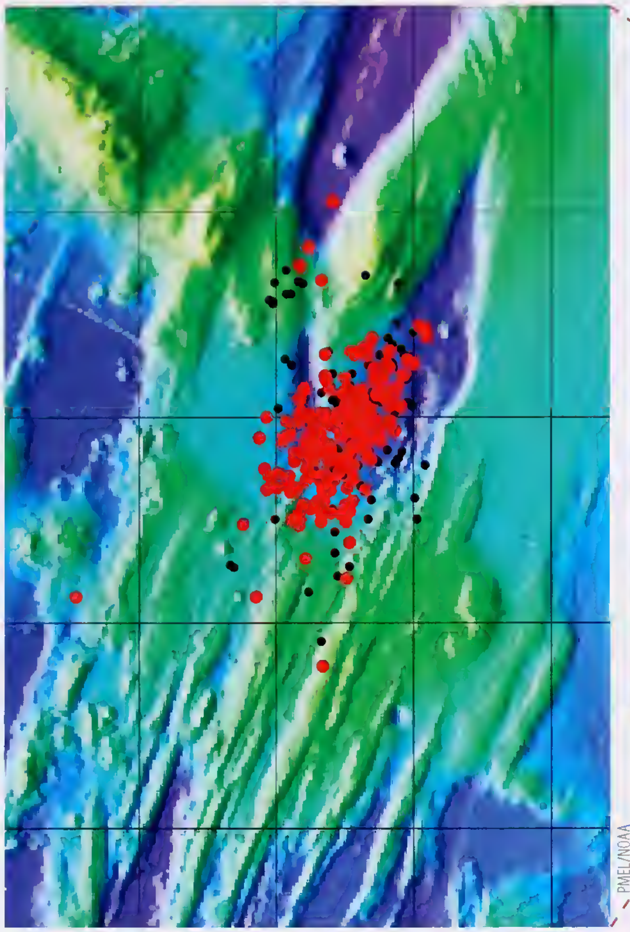
▲ WHOI postdoctoral fellow Rhian Waller (left) and University of Washington graduate student Deb Glickson were among the scientists who tried to witness an undersea volcanic eruption in action. During the expedition to the Juan de Fuca Ridge aboard the R/V *Thomas R. Thompson*, scientists used a towed camera system, shown in front, to find evidence of volcanism.

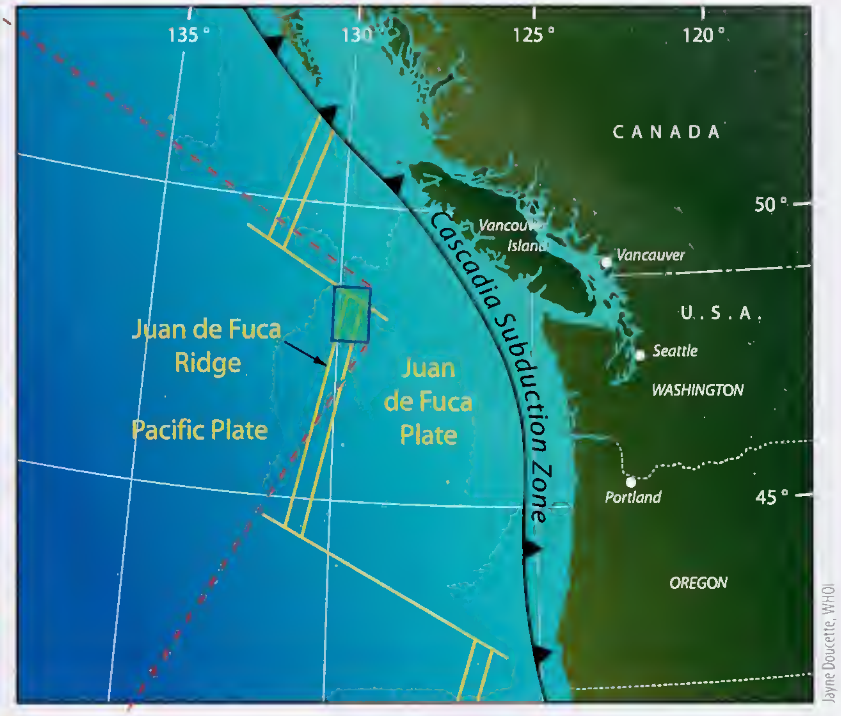
"Oceanographers have a built-in handicap because we so rarely have an opportunity to view undersea earthquakes and eruptions happening in real time," said geologist Dan Fornari, director of the Deep Ocean Exploration Institute at Woods Hole Oceanographic Institution (WHOI). "We're missing a piece that helps us understand how Earth formed and constantly reshapes."



WHOI TowCam

► Scientists searching for undersea volcanic eruptions are looking for evidence of fresh lava. This lava, photographed on the Galápagos Rift in 2002, was estimated to be less than 10 years old. As lava ages, it loses its glassy black luster.





On Feb. 28, 2005, an undersea hydrophone network began detecting the most intense swarm of earthquakes to occur in the last three years along the Juan de Fuca Ridge, about 320 kilometers (200 miles) off the Pacific Northwest coast. Each red dot represents an earthquake epicenter. Within five and a half days, the hydrophones had detected 3,742 earthquakes.

Fornari was among the scientists around the country who helped mobilize the quickly assembled expedition, launched March 5, to try to capture unprecedented data on undersea eruptions as they are happening.

Since 1993, the National Science Foundation and the National Oceanic Atmospheric Administration have funded six such rapid-response expeditions off the Pacific Northwest, where an undersea surveillance system (originally built to track Soviet submarines) provides signals from earthquakes. On five expeditions, “we have seen some smoking guns,” said oceanographer Robert Dziak, who monitors offshore activity from his laboratory at the Hatfield Marine Science Center at Oregon State University. These included chemical plumes in the water that indicate the presence of hydrothermal vents, as well as freshly erupted lava, which looks glassy and black on the seafloor.

“Each time we go out we get a little bit closer to seeing things happen in real time,” said Dziak. “We still haven’t caught it within a few days. But this was our fastest time getting out there yet.”

Oceanographic expeditions typically take three to 12 months to plan and coordinate. The most recent trip, organized by oceanographer Jim Cowen at the University of Hawaii, came together in six days.

“It was pretty frantic, like an oceanographic SWAT team,” said geologist Bill Chadwick of Oregon State University.

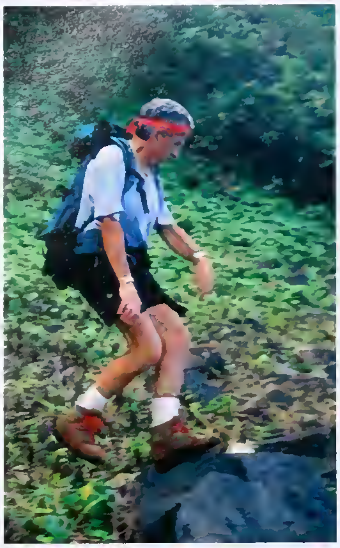
Research equipment, much of it shared between U.S. oceanographic institutions, was identified, shipped, and re-assembled. R/V *Thomas R. Thompson*, one of 28 research ships operated in the U.S.—and a vessel typically booked months in advance—happened to be available in Seattle. Crew members, including the captain and two dozen engineers and technicians, rearranged their time ashore to run the vessel and support science work. Twenty scientists from five states and Canada dropped research projects and family obligations for a 20-hour cruise to the earthquake region.

Marshall Swartz, a research associate in WHOI’s Physical Oceanography Department, said he didn’t sleep for four nights as he helped to arrange for the various parts of a towed undersea camera system to be sent from Hawaii, California, and Massachusetts for use on the vessel.

Once on board, he and WHOI postdoctoral fellow Rhian Waller spent hours at shipboard computers remotely guiding the camera system thousands of meters below the sea surface and maintaining it at specified heights above the seafloor to map the area for evidence of volcanism.

By the end of the cruise, scientists determined that the quakes occurred too deep within the Earth to send fresh lava up to the seafloor. Still, “the experience was worth the hustle,” Swartz said. Hundreds of photos, dozens of chemical samples, and a wealth of sonar data will be analyzed in the months ahead, offering more clues and insights into deep-sea activity.

—*Amy E. Nevala*



Rhea Workman, WHOI

Geochemist Stan Hart

Hart elected to American Academy of Arts and Sciences

Senior Scientist Stanley Hart of the WHOI Geology and Geophysics Department has been elected a Fellow of the American Academy of Arts and Sciences, one of the oldest learned societies in the nation.

Hart is a geologist and isotope geochemist whose recent research has focused on the origin of hot spots and mantle plumes and on the dynamics and evolution of the deep Earth. (Read more at oceanus-mag.whoi.edu.)

The academy was founded in 1780 by John Adams, James Bowdoin, John Hancock, and other scholar-patriots. According to the academy's announcement, it has elected "the finest minds and most influential leaders from each generation."

Over the years, its membership has included George Washington, Ben Franklin, Daniel Webster, Ralph Waldo Emerson, Albert Einstein, and Winston Churchill. This year's inductees included the artist Maya Lin, Supreme Court Chief Justice William Rehnquist, and Nobel prize-winning physicist Eric Cornell.

WHOI Associates have a new president

Carl Peterson said he "grew up practically next door to Woods Hole Oceanographic Institution" and has been "involved with the Institution in one way or another ever since." In May, Peterson became involved in a new way: He was named president of the WHOI Associates, whose membership supports research at WHOI.

"From childhood in Woods Hole, the Oceanographic has always been a presence in my life," Peterson said. "The father of a friend was captain on a WHOI ship. The Institution's third director, Admiral Edward Smith, was a close family friend. And my own father designed the Smith Laboratory, WHOI's second building, which was named after our friend.

"My wife, Pancha, and I have been WHOI Associates for 25 years and consider membership a unique opportunity to learn about a largely undiscovered part of our planet," he said.

Peterson succeeds Dudley Harrington Jr., who was president for more than a decade. "Under Dudley's leadership," said WHOI President and Director Bob Gagosian, "the Associates have flourished. His effort has added immeasurably to the vitality of WHOI and also to a wider public awareness of the importance of understanding our oceans."

Alec Peterson

Carl and Pancha Peterson

WHOI Associates span 38 states and nine countries. They receive the magazine *Oceanus*; invitations to events and lectures; opportunities to visit destinations around the world; a 15 percent discount on WHOI Gift Shop merchandise; and free admission to more than 270 science centers and museums. For more information, contact Lesley Reilly at associates@whoi.edu or 508-289-3313.

Dave Gray, WHOI

Dick Pittenger and Allison Berg

Pittenger Fellowship awarded to naval graduate student

WHOI presented its first Rear Admiral Richard F. Pittenger Fellowship in March to Ensign Allison Berg, a master's degree candidate in the MIT/WHOI Joint Program.

The Pittenger Fellowship, to be awarded annually to a U.S. naval officer in the Joint Program, was established to honor the Institution's former vice president of marine operations, who retired in 2004 after 14 years at WHOI and 32 years in the Navy, including a tour as Oceanographer of the Navy. He is a strong advocate for science and engineering education for naval officers.

"It is an honor to be presented with an award that recognizes such a great naval officer," said Berg. "I am grateful for Admiral Pittenger's service to our country, as well as his genuine efforts at WHOI." Berg will work with WHOI Research Specialist Eugene Terray on a project using Sonic Detection and Ranging (SODAR) to detect air-sea interactions. Read more at whoi.edu.

Newest *Alvin* pilot comes aboard

Gavin Eppard became WHOI's newest *Alvin* pilot on March 21, making his first solo dive on an expedition to a submerged mountain range on the East Pacific Rise, about 4,400 kilometers (2,000 miles) west of South America. He is the 35th person to complete pilot training for operation of the 40-year-old submersible.

Eppard, 34, has spent approximately eight months a year at sea on R/V *Atlantis* since June 2001 to complete his training. It includes learning nearly 200 mechanical, hydraulic, computer, and electrical systems needed to operate *Alvin* and completing several oral examinations on operational systems, scientific sampling, engineering, and safety. *Alvin* pilots-in-training also make several dives with pilots before diving solo.

Amy Nevala, WHOI

Alvin pilot Gavin Eppard

Remembering a scientist/ student/artist

Celeste Fowler joined the MIT/WHOI Joint Program (JP) in June 2003 and quickly made her presence felt. She was a "fantastic" engineer in the Deep Submergence Laboratory, said her adviser, Hanu Singh. But she also had "this whole other artistic side to her," said Anna Michel, a JP student who worked with her. "She always had a lot of energy… She always had her camera and was taking pictures." She also found time to volunteer to give tours for the WHOI Information Office.

After Fowler was diagnosed with metastatic melanoma, her colleagues watched as she confronted her illness with "unbelievable dignity," Singh said. "Her experience was an education for everybody." She died eight weeks after her diagnosis, in March 2004.

After she graduated from Princeton with a degree in computer science, Fowler worked for Silicon Valley companies, but all the while indulged her artistic and athletic side: scuba diving, skiing, traveling, and always taking photos. In 2000, she combined her passions for diving and photography, working for SeaPics.com, a stock photo company specializing in marine life.

When JP students expressed a desire to commemorate Fowler, John Farrington, vice president for academic programs at WHOI, suggested a way that would remember her as both scientist *and* artist—an art show.

Along with some of Fowler's photos, 16 JP students displayed their paintings, pottery, photography, woodworking, metalwork, drawings, macramé, jewelry, and knitting. Two gave musical performances; one presented a monologue.

"It celebrated the diversity of our students' talents, beyond the academic," Farrington said.

The Celeste Fowler Memorial Art Show will now be an annual event.

—*Lonny Lippsett*

Dana Yoerger, WHOI

▲ "It was a beautiful October day," said WHOI scientist Dana Yoerger, "and I was walking to the Blake building, past a field of cosmos. It was filled with Monarch butterflies. So I ran to get my camera, and I said to Celeste, 'Quick, grab your camera.' Her photographs of the butterflies on the flowers were beautiful. All mine turned out lousy—except for this one."

Tom Kleindinst, WHOI

▲ Vicky Cullen, director of 75th anniversary activities at WHOI, brought an exhibit of historic oceanographic instruments, drawn from the WHOI Archives collection, to the Clark Laboratory lobby.

Institution celebrates 75th birthday in 2005

WHOI celebrates 75 years of ocean research, education, and exploration this year with several events planned for August and September.

- A fleet of unusual water craft will parade in Woods Hole's Great Harbor in an **Anything-But-a-Boat Regatta**, Aug. 6.
- **Down to the Sea for Science**, a 184-page book depicting WHOI history in words and pictures, written by Vicky Cullen, is scheduled for delivery in August.
- A **public open house**, the first in 25 years, Sept. 10.
- A **two-day symposium** featuring six scientific themes, Sept. 21-22, followed by a day of activities for MIT/WHOI Joint Program alumni/ae and commencement on Sept. 24.

More information on these events is posted at www.whoi.edu/75th, along with a series of weekly word-and-picture portraits of WHOI employees through the years, and anniversary merchandise, including a jacket, shirts, shorts, a pen, a mug, a keychain, and a photomosaic poster combining 4,500 photos from the WHOI Archives into an image of the Institution's first open-ocean research vessel, *Atlantis*.

WHOI announces $200 million capital campaign

◄ Two new buildings—a 36,000-square-foot building devoted to the emerging cross-disciplinary field of biogeochemistry (left) and a 32,000-square-foot marine research laboratory—are scheduled for occupancy this fall on the WHOI Quissett campus.

Tom Kleindinst, WHOI

A total of $118 million donated or pledged; $82 million left to raise—that was the tally as WHOI emerged from the "quiet" phase of its capital campaign and announced the public phase at its Board of Trustees meeting in January.

WHOI Director of Development Dan Stuermer said the first phase of the campaign secured funds to:

- build R/V *Tioga*, WHOI's 65-foot coastal research vessel, launched in 2004;
- construct two new buildings—a 32,000-square-foot Marine Research Facility and a 36,000-square-foot biogeochemistry building—which should be ready for occupancy by fall of 2005;
- launch the four WHOI Ocean Institutes: the Ocean Life Institute, the Coastal Ocean Institute, the Ocean and Climate Change Institute, and the Deep Ocean Exploration Institute.

"The Ocean Institutes have disbursed $12 million in research funding to 128 scientists, engineers, students, and postdoctoral scholars through 2004," Stuermer said. "They have often funded high-risk, high-reward research or innovative projects that joined biologists, chemists, geologists or physical oceanographers. Such research is harder to fund via traditional federal funding. But privately seeded research has demonstrated proofs-of-concept that have advanced our knowledge and that have often leveraged significant further research funding."

As the campaign marches on, major goals include endowments to secure the future of the Ocean Institutes and to fulfill the Access to the Sea (ATS) Initiative, Stuermer said. The ATS Fund supports new approaches for seagoing research, including the development of new technology (vehicles, observatories, and sensors), ship time for scientists, engineers, and students, and funding for scientifically critical but expensive exploratory expeditions in remote locations.

A tropical research paradise

WHOI Trustees Frank and Lisina Hoch have issued a one-to-one $1.125 million challenge to seize new opportunities and expand the Institution's research in tropical regions.

The $2.25 million Tropical Research Initiative is timed to take advantage of an "unusual opportunity," said Frank Hoch: the newly constructed Liquid Jungle Lab (LJL), a well-equipped "scientific village" built by businessman Jean Pigozzi on land he owns on the Pacific coast of Panama. "The land is unspoiled and virtually uninhabited—a researcher's paradise," Hoch said.

Scientists from WHOI, the Smithsonian Tropical Research Institute, and the Royal Botanical Garden of Madrid provided integral scientific and technical advice on the design and operation of LJL. The site offers an undisturbed coastal site where ocean scientists can explore plankton, viruses, dolphins, jellyfish, corals, reef fish, mangrove swamps, and coastal currents, said Larry Madin, director of the WHOI Ocean Life Institute.

"The tropics are filled with an unimaginable variety of life, and they are under-researched," Hoch said. "We hope to extend WHOI's expertise into tropical regions."

Beyond Panama, the Initiative is already helping to launch new research by WHOI scientists on coastal changes in Indonesia caused by the Dec. 26, 2004, tsunami (see page 24).

Tom Kleindinst, WHOI

▲ Ocean Life Institute Director Larry Madin (center) displays jellyfish to Lisina and Frank Hoch at the WHOI Trustees meeting in May.

Guy Nichols: transforming institutions

Guy Nichols never shied away from tough jobs. And he never lost sight of the fact that an organization needs all its people, not just those at the top.

In the 1970s and 1980s, Nichols led New England Electric System through oil shortages, strikes, deregulation, and public jitters over nuclear power. By the time he left the job, he had transformed the publicly traded power company from one with some of the highest prices and operating costs in New England to one of the most efficient, customer-friendly, and profitable. For this, he was named "New Englander of the Year" in 1984.

Yet even after he became chief executive, he was legendary for visiting employees in the plants and at construction sites, never forgetting his roots as a foreman and civil engineer. "I grew up in the operating and distribution side of the industry," Nichols said. "The most interesting job I ever had was serving as a general foreman because you were building things all the time."

His tenure as Chairman of the Board of Trustees for Woods Hole Oceanographic Institution from 1985 to 1995 followed a similar arc. He worked with three directors—John Steele, Craig Dorman, and Bob Gagosian—saw two of the Institution's three ships get retrofitted and refurbished, and helped WHOI become more selective and competitive in its recruiting and tenure practices. He provided counsel as WHOI transitioned from a Cold War funding model fed only by federal dollars to a blend of government grants and private donations in the leaner 1990s.

"Guy was the steadying hand during a time of apprehension," said Jim Clark, long-time chairman of the WHOI Corporation. "He kept the Institution on course during rather hectic and distracting times." He also helped lead the Institution's first capital campaign, which raised nearly $55 million.

"Guy has worked tirelessly for WHOI," said Gagosian, who became director of WHOI on Nichols' watch. "He asks the right questions and can make

WHOI Archives

the tough decisions, and he deserves a lot of credit for the current shape of the Institution."

All that time, he went down into the village of Woods Hole to have coffee with WHOI staff *before* heading off to executive committee meetings.

"I liked going to the local coffee shop to find out what WHOI people were thinking about," Nichols recalled. "I always enjoyed asking Henry Stommel, Stan Watson, or Holger Jannasch about the latest idea they were kicking around," he said, referring to three WHOI scientific giants.

Though he has been associated with WHOI for three decades, he still looks at every new science talk with the wonder of his first visit. "It's the scientists and engineers that attract me," Nichols said. "I have been fascinated by the instruments that the WHOI shops produce and put to work under terrible conditions. For anybody who's tried to keep the relatively simple electronics aboard a sailboat operational, you get impressed by the engineering of WHOI."

His leadership has continued though his official tenure has ended. Nichols and Clark co-founded WHOI's Paul M. Fye Society for planned giving, and Nichols was the first donor to the pooled income fund.

"WHOI continues to be very reliant on federal funding, yet it is very difficult for the government to fund ideas in their initial stages," Nichols said. "I think it is important that we provide WHOI with unrestricted funds to support the initial stages of research that may turn out to be a disaster but also may turn out to be a great idea."

— *Mike Carlowicz*

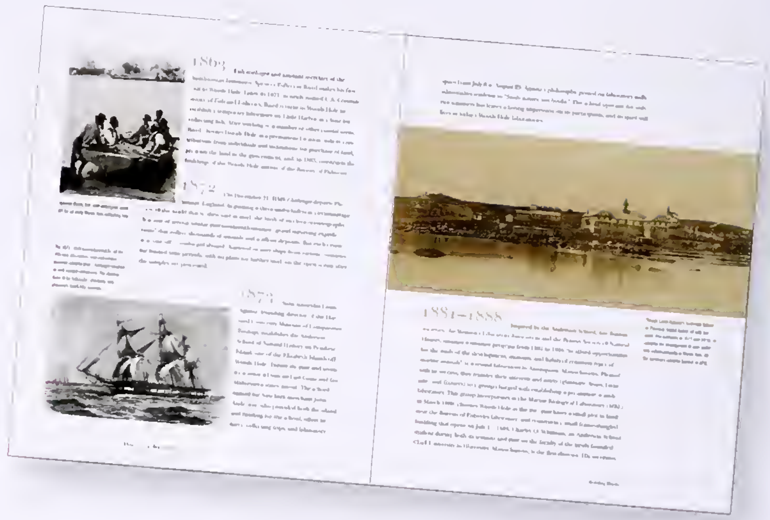
Through charitable bequests, life income gifts, and trusts, members of the Paul M. Fye Society help build the WHOI endowment and promote the next generation of ocean explorers. For more information, contact Lesley Reilly, director of planned giving, at 508-289-3313 or lreilly@whoi.edu.

Down to the Sea for Science

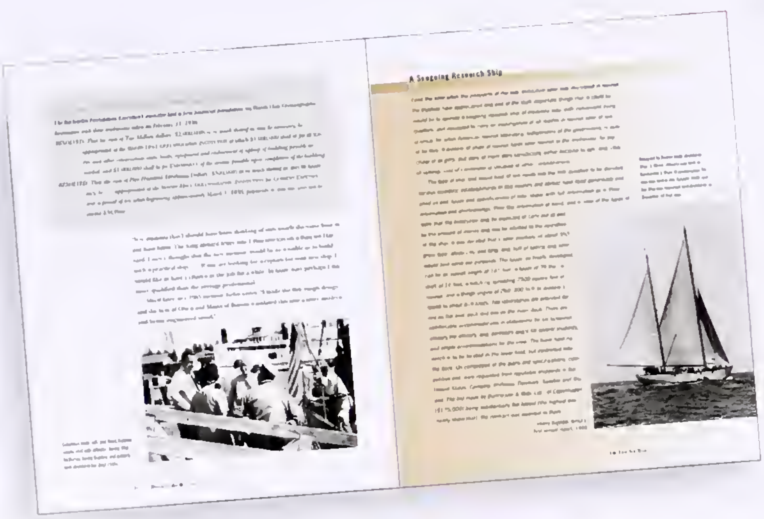
75 Years of Ocean Research, Education, and Exploration at the Woods Hole Oceanographic Institution

BY VICKY CULLEN

Woods Hole Oceanographic Institution (WHOI) has been a major player in ocean science since its founding in 1930. In 184 pages, *Down to the Sea for Science* not only chronicles the growth of this institution but also offers broader insights into U. S. science at sea during the twentieth century and beyond.



Chapter 1 (1863–1929) describes influential personalities and events that led to establishment of an oceanographic laboratory on the U.S. East Coast, where WHOI joined an already thriving research community in Woods Hole, Massachusetts.



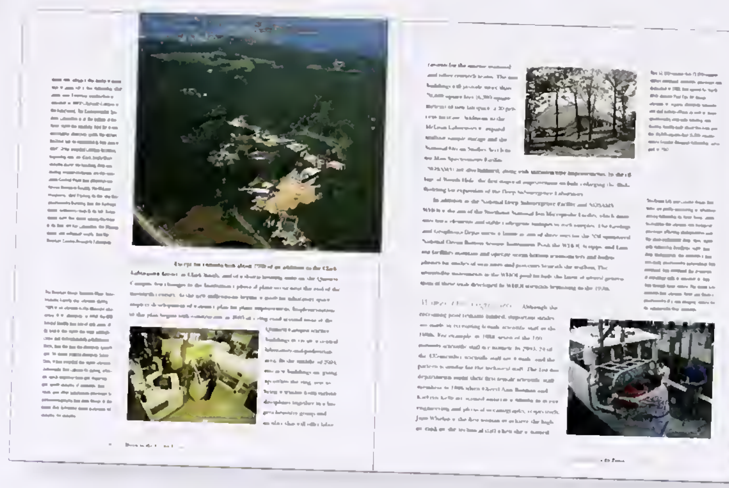
Chapter 2 (1930–1939) begins with incorporation of the new institution on January 6, 1930, and describes planning and construction of the first laboratory building (still in use today) and the first research vessel, the 142-foot ketch *Atlantis*. It follows the early research staff gathering in Woods Hole each summer "to prosecute the study of oceanography in all its branches," as promised in the Institution's charter.

Science Story Lines follow six threads of research from the early days of WHOI to the present. Representing thousands of research projects conducted in various fields over the Institution's seventy-five years, these stories discuss investigations of the Gulf Stream, air-sea interaction, and gelatinous animals ("jellies") along with marine geology and geophysics, chemistry, and microbiology.

Chapter 3 (1940–1958) describes the Institution's growth from a summer marine research station to a bustling year-round laboratory devoted to war-related questions ranging from investigation of marine "fouling" of ships to study of underwater explosives. It follows researchers' return to peacetime studies and the young institution's path toward strength in an inflationary postwar economy.

Chapter 4 (1959–1979) chronicles twenty years of astonishing growth for WHOI in a time of increasing national interest in science. New, large research vessels and a submersible take oceanographers around the world and into the deep sea for wide-ranging investigations of oceanographic phenomena. While emphasizing "wise use of the ocean," the Institution establishes marine-policy and graduate-education programs and expands to a new campus.

Chapter 5 (1980–2005) introduces today's Woods Hole Oceanographic Institution, a world leader in marine science. Continuing its rich tradition of excellence in research, WHOI also maintains its reputation for highly skilled marine operations and innovative development of scientific instrumentation.



Down to the Sea for Science

Ordering information online at: www.whoi.edu/75th/book/index.html
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Joe Pedlosky

Fathoming the ocean without ever going to sea

On a softball field, Joe Pedlosky plays a respectable first base, sporting a cap that sprouts Hermes-like wings. But in the field of physical oceanography, he is a bona fide star. In January 2005, the Woods Hole Oceanographic Institution senior scientist was awarded the prestigious Sverdrup Gold Medal of the American Meteorological Society, given to researchers who make outstanding contributions to the knowledge of interactions between the oceans and the atmosphere. Not bad for an oceanographer who has never gone on a research cruise.

At cocktail parties or around the Thanksgiving table, how do you answer the question: "So, what do you do?"

I try to explain the motion of the ocean.

Physical oceanography is the quest to discover and understand how the ocean is moving, over space and time, on a wide range of scales: From the moon-driven tides to large waves that span the entire planet and are only visible in satellite data; from so-called rapid surface gravity waves, like the recent tsunami, to internal waves—which are heaving motions along layers *within* the oceans—to the persistent general circulation of currents and gyres. All the physics needed to unravel this wide variety of motion can be described using the same basic mathematical/physical laws that Newton used to describe the motion of the planets in their orbits.

So, this makes me a theoretician. I never go to sea—except conceptually. I work with paper and pencil and computer.

What encouraged you to pursue this line of work?

In 1960 I was an aeronautical engineering student in love with aerodynamics—the dynamics of flowing air. I answered an advertisement for the now venerable WHOI Geophysical Fluid Dynamics summer seminar program, which had just started the year before. It offered the promise of a summer on the Cape while doing fluid dynamics, two things I greatly enjoyed. I had no intention of becoming an oceanographer, and I believe I said so on my application. They took me anyway.

I had a splendid research experience that summer with Melvin Stern, who is not only a brilliant scientist, but was a kind and encouraging mentor to me. He made me realize that fluid mechanics was even richer than what I had been experiencing in my engineering courses. Soon after, I fell under the inspiring influence of Professor Jule Charney in the Meteorology Department at MIT, with whom I did my Ph.D. thesis.

I remember one hair-raising ride down to Woods Hole from MIT. Jule was driving, paying no attention to the traffic, and explaining to me how he felt connected—through a generation-spanning series of his mentors, and their mentors, and the mentors of those mentors—all the way back to the great 19th-century physicists who were his heroes. This was an invitation for me to feel similarly connected to the communal scientific effort since the Enlightenment to understand our world.

You earned the Sverdrup medal for your "theories of the general circulation and baroclinic instability." Would you translate?

The general circulation of the ocean is a massive and majestic phenomenon. The mass of water in the Gulf Stream that rushes past Cape Hatteras every second is greater than the weight of all the people in China! This grand sweeping circulation of the ocean is driven by an ensemble of physical causes—like the action of the wind on the ocean surface or the uneven heating and cooling of the ocean by the sun.

These physical forces lead to variations in temperature and densities within the ocean and atmosphere—a situation that is inherently unstable. A broomstick balanced upside down, for example, is in an unstable equilibrium position. If it is even slightly disturbed, it will quickly tumble. Potential energy is converted to kinetic energy.

Similarly, even the smallest disturbances in the Gulf Stream in the ocean, or the Jet Stream in the atmosphere, will release waves, which bring us our weather in the atmosphere and result in eddies and meanders in the ocean. This is the so-called butterfly effect. The theory that describes these phenomena is called baroclinic instability.

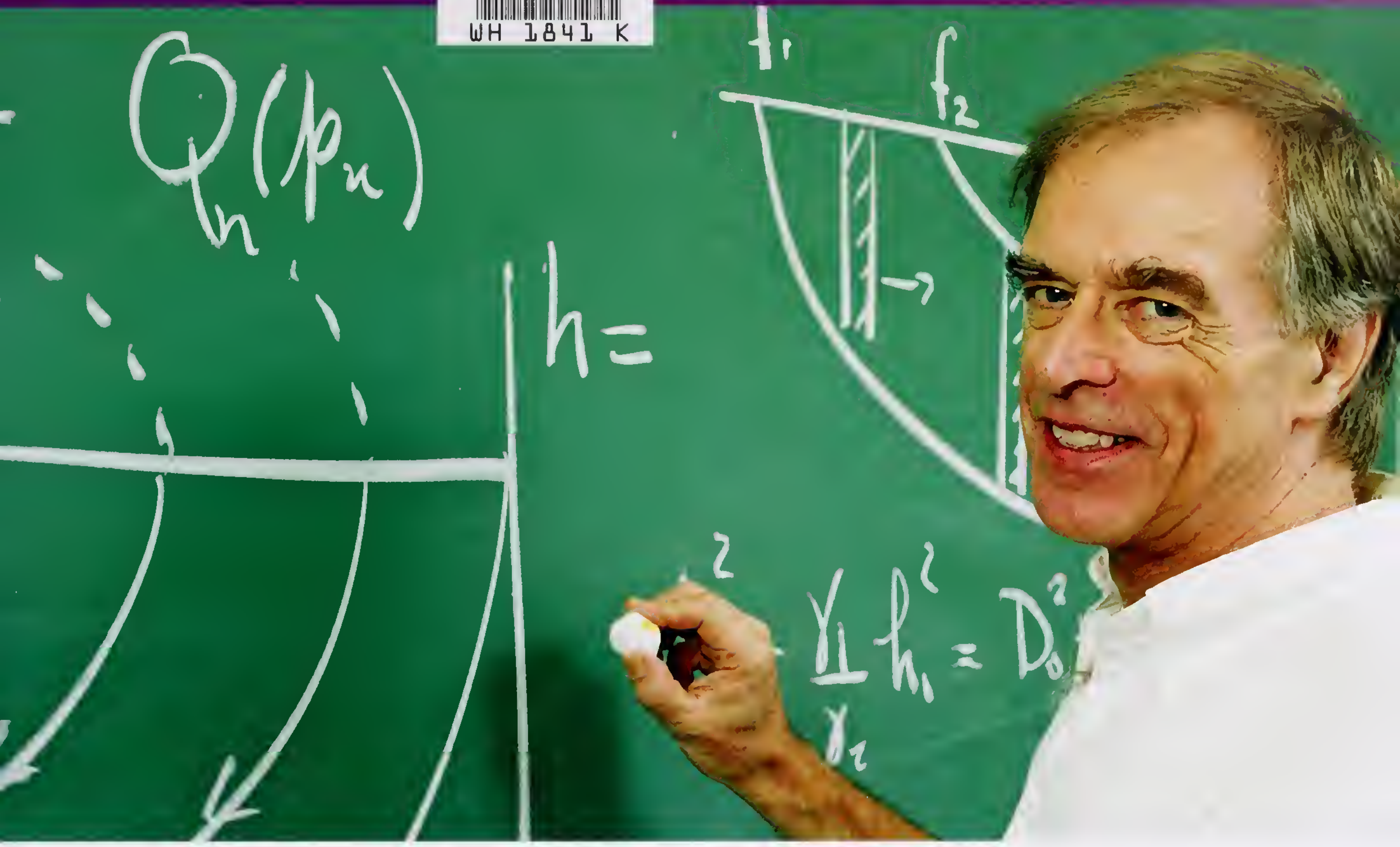
At the age of 34, you were a full professor at the University of Chicago. Why did you give that up to work at WHOI?

I loved the University of Chicago. I left it with great sadness, but I felt at the time that the general intellectual stimulation of the university was not enough to balance the opportunity to interact with so many truly fine researchers in my own scientific area of interest here in Woods Hole.

Like all creative efforts, an oceanographer's work is often solitary. Ideas come at all times; realizations of error come unbidden in the small hours; and brooding over an unsolved problem has no schedule. Research is an intensely personal activity, but it is also a deeply human one: Collaborations and interactions are an indispensable stimulant—a chance remark over lunch, a criticism at coffee time, supportive enthusiasm at a seminar.

Though I stick close to my desk and never go to sea, I work in concert with people who *do* go to sea. They collect observations against which my theories are tested, and which also suggest the need for new theories. I have learned much from my colleagues.

All that said, I would not have given up the security of salary



"I try to explain the motion of the ocean," says WHOI physical oceanographer Joe Pedlosky. "I am a theoretician. I never go to sea—except conceptually. I work with paper and pencil and computer." And sometimes chalk and chalkboard.

support at Chicago if I hadn't received similar support at WHOI. The tension and pressures of constantly having to raise one's own salary by submitting research funding proposals for competitive review is a necessary evil, but it does not in itself sharpen the quality of one's work. In my experience, scientists on "hard money" work no less hard and are no less creative. Stable support is essential: It permits long lines of thought or experimentation on hard, risky problems.

What do you hope to achieve with your work?

I have hoped to contribute to the understanding of the inner workings of the ocean and the atmosphere.

But an equally honest answer is that the challenge and the satisfaction for the theoretician is to see, unfolding on the page before him, a mathematical consequence of basic laws of physics that tell us, for example, "Well, yes, there should be an Equatorial Undercurrent, and this should be its characteristic width, depth, and speed, and this is why it is there." You can understand the enormous personal satisfaction of seeing that explanation unfold—first to you alone. It must be like the satisfaction that artists feel in seeing their paintings capture the essence of a person or a landscape.

You've described your scientific endeavors in terms of journeys, history, and art. Have you pursued these in nonscientific ways?

My family and I have spent parts of many years in Italy. There is an elegance to Italian cuisine, grace in its people, and beauty in its art—characteristics that all theoreticians aspire to in their work.

Italy for me is largely Venice, which, after all, is a city that lives in water. Water and its motion and its effects on light are everywhere. I started playing with rainwater in the gutters and alleyway puddles of Paterson, New Jersey, as a boy, and now I get to enjoy the canals of Venice. That, certainly, is some progress.

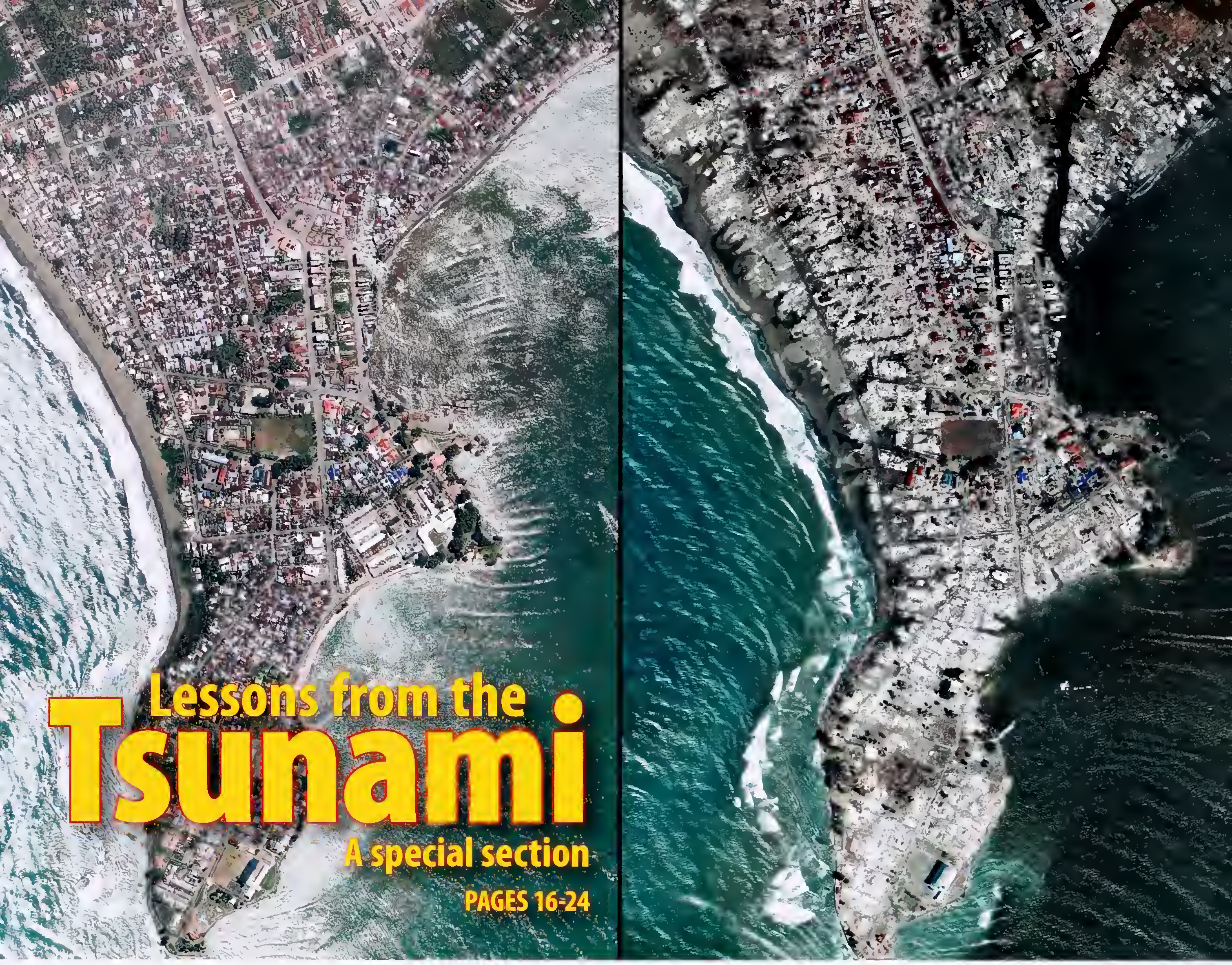
I also play the clarinet, which brings to mind the terribly destructive saying that "anything worth doing is worth doing well." It simply isn't true. I will never be a very good clarinetist, having started late in life, when I was 40. But the pleasure of playing is very important to me, and if it does not meet someone else's standard, I choose not to worry about that. Mozart hasn't complained, or can't, and fooling around with jazz is my democratic right.

And then there's baseball. Tell us about your winged cap.

Shortly after I arrived in Woods Hole, two close friends presented me with my winged hat—a tribute, I think, to my slowness on the base paths. Sometimes I meet people from other teams who recognize me only after I introduce myself as the man with the winged hat.

Baseball is surely a scientist's game. After all, a great batter mostly fails; the very good ones fail two-thirds of the time, and that is a great lesson. If you try to do something very hard like hit a baseball or explain the circulation of the ocean, be prepared to fail, and often.

—Lonny Lippsett



Satellite images of the Indonesian town of Meluaboh on May 18, 2004 (left), and Jan. 7, 2005 (right), show the destruction wrought by the Dec. 26, 2004, Indian Ocean tsunami. Photos courtesy of DigitalGlobe.

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